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EXPLORATION FOR ORE DEPOSITS.[1]

T. M. BRODERICK.

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INTRODUCTION.

OUR Society is made up of men whose interests are in various phases of economic geology and the presidents are chosen so that these various groups get their turn at being represented. I have been chosen as the representative of the mining geologist group, and my talk will deal with some of their problems.

At the close of World War II anxiety amounting almost to desperation was felt over the depletion of mineral resources resulting from the conflict. This was especially true in the United States, the "Arsenal of Democracy." All over the world, exploration is being speeded up tremendously in a determined search for minerals, especially those essential to "defense."

Because of the vast sums being spent, and the increasing difficulty of finding new mineral deposits, it is timely to inquire as to how exploration can be improved. The responsibility for the planning and conduct of exploration is primarily in the hands of the mining geologists and all of these

[1] Address by the retiring President, Society of Economic Geologists, San Francisco Meeting, February, 1949.

men recognize that their work for various reasons is not done most effectively. While we have heard and read on occasion what the educators, the mining executives, and others think would be desirable improvements, it occurred to me that the mining company geologists might be given an opportunity to express themselves. The observations which I have gathered are in part my own and in part contributed in communications, both oral and written, with a selected group of geologists, the majority of whom are or have been in charge of exploratory work in North America for various mining companies.

In collecting these observations it very soon became apparent that these men thought that numerous people and organizations shared the responsibility for effective conduct of explorations. These include the geologists themselves, the mining company managements, the educators, the Federal and State Surveys and Bureaus, the technical press, our lawmakers, and others.

I wish to express my indebtedness to those who have responded so generously to my request for their opinions. I hoped to get enough replies—and did—from those in charge of explorations to enable me to feel that what I am about to say is the opinion of responsible members of our group. While there have been interesting differences of view on some questions, there has been a general agreement on important topics.

My correspondents have on the whole been impersonal in their communications. The dissatisfactions which will be mentioned are not to be regarded as my own or as those of any other individual, but as my interpretation of various elements which the profession regards as making for inefficiency in exploration.

Geology is making a creditable record in exploration. Very imposing lists of discoveries in recent years have been drawn up, and even if we eliminate those which some of us think should not be included for one reason or another, nevertheless there is an impressive residuum of genuine discovery to be credited to geology. However, since the hope for discovery lies in buried or blind deposits, it is likely that the difficulties and cost of discovery will continue to outstrip any expectable development of skill in exploring.

I shall have a few things to say about the education of a mining geologist, then touch upon other qualifications which he should have; what sort of men he may have to work for; the different attitudes toward exploration by different companies; how his job compares with teaching or government work, etc. The methods of exploration themselves are receiving ample treatment nowadays and they will not be discussed here.

EDUCATION AND TRAINING.

It is pretty generally recognized that there are two types of mining geologists. Many of their characteristics are common to both types but if we take the extremes of each we might summarize them as follows. As will be noticed, certain fundamental elements of personality are involved which make it unlikely that the same attributes can be developed in every man.

Type I—the scientific—is introspective, imaginative, interested in geology

as a science, takes a Ph.D. degree with a dissertation dealing with principles; is interested in the correlation and synthesis of data; he may evolve some theories of great importance; is interested in finding a new district rather than a missing faulted block; he might ultimately go into University or Survey work, or if he sticks with his company he will more likely wind up as Chief Geologist as the climax of his career rather than in a higher position elsewhere in the organization.

Type II—the geological engineer—an extrovert, "practical," he flourishes a slide rule, keeps his feet on the ground, takes a degree in mining engineering, may discover ore bodies but not districts, emphasizes details, collects data and files them away, may be a very useful jack-of-all-trades, a plumber, a lawyer, joins the churches, lodges and Babbitt clubs, he is given the "green light," he "streamlines" his work, speaks of the "overall picture," etc., is promoted to executive work, and may become the boss of his former associates, the Ph.D's of type one.

The former dreams up things to do and the latter gets them done. Besides these extreme types there are the intermediates and others, perhaps some of them not so strictly geologists, such as the geophysicists. Educators should realize that all of these are important and should not make their requirements and courses too rigid. They should resist any tendency to make a geophysicist out of every student who wants to become a geologist. The geophysicist must be guided by precise data, but the flights of untrammeled imagination necessary to conceive an exploration for a new district cannot be circumscribed by the requirements of the geophysicist. Some company departments are large enough so that they can employ geologists of varying talents.

Many students realize that the professors of economic geology are specialists and that it is often well to spend their post-graduate years in one or two institutions other than their alma mater.

There is some difference of opinion as to the value of the doctorate to a mining geologist. It often does not "pay off" until later in his career. One man who has had contacts with many mining geologists says that the Ph.D.'s seem to have a greater feeling of belonging to a profession, the others are more inclined to be just "employees."

The desirability of acquiring field experience along with academic training is recognized. The least which the student can do is to take summer field courses or obtain summer geological employment. Even more desirable would be to interrupt his academic work somewhere at the end of the general courses and before the specialized or research courses, for a year or more in the field working for a government survey or a mining company. Then, on reentering college, he would have more confidence on taking up his advanced work. This would also ease the shock of transfer from college to his job because he would be continuing along a path on which he already had gotten a start. Not only does the student gain by this early apprenticeship, but his employers and his instructors also.

During the war the emphasis was upon quick results and the so-called "practical" man was in the saddle. The warning has been sounded that our

profession will suffer if we do not return to the realization that we must turn out a good proportion of mining geologists with a truly scientific attitude and foundation.

The educator has a tough job in hitting the right balance between letting a student know the uncertainities in economic geology, and at the same time preventing him from getting a cynical or discouraged attitude. He must learn that even in the case of the oldest and longest-studied districts there are still profound differences of opinion as to important features of the genesis of their ore deposits. We need only to mention some examples like the Rand, Sudbury, Lake Superior iron, Homestake, and the sandstone deposits of the Colorado Plateau; also the relationship of ore deposits to igneous rocks, to structure, the source of ore depositing solutions, their character, both physical and chemical, the facts about zoning, the role of gouges (barriers or semi-permeable membranes), sources of metals (direct magmatic contribution or leaching from sediments and reconcentration) and if the latter, by hypogene or supergene solutions, etc., etc. He must learn that in spite of these differences of opinion, there is one sure thing and that is, if economic geologists who know the facts of occurrence cannot resolve them, no one can.

PERSONAL QUALITIES WHICH A MINING GEOLOGIST SHOULD HAVE.

Desirable personal characteristics of a mining geologist received much emphasis. In considering what is of greatest importance as a foundation for a career in mining geology, those of imagination and salesmanship rank right up at the head of the list with education and training.

The possession of intuition was mentioned but by this was not meant a blind hunch. It is probably an ability to make a subconscious judgment based upon experience. One might logically draw the conclusion that the more experience one has had, the more ore bodies he has studied, the keener his intuition. Thus the intuition of the mature would seem to be more reliable than that of the youth. Our recognition of the existence of such a quality does not necessarily mean that we are impressed by those who assert the keen functioning of their sensitive "nose for ore," or those who claim the gift of being able to size up any property in a few hours.

Another quality emphasized is that of imagination. We know that as children we have a vivid imagination. We tell stories about our adventures in far-off places, with a keen conviction of their truth. As we get older, our imaginations became curbed. We may be told that lying is a sin, or we may be ridiculed, and in any event our early, unrestricted imagination becomes limited as the development of reason and observation progresses.

Without imagination a mining geologist becomes a routine creature indeed. Here again is where age vs. youth—or put another way, experience vs. inexperience—should receive consideration. Youth should have more of the original stock of imagination remaining, but on the other hand youth does not have the anchors provided by a background of experience. Thus in normal life, as the stock of imagination declines, there is, for compensation, an increase in the capacity for sound judgment based upon experience.

There are ways to offset the decline in imagination as judgment increases. One way is for the youth to lose no opportunity to build up his bank of experience as early as possible. His early work should include chances to see many mining districts and to work with highgrade mining geologists in the field. Another possibility is for him to keep, or even develop, his imaginative faculty throughout his life. I can think of no faculty the retention or development of which is more important for the economic geologist than that of scientifically controlled imagination.

Other qualities of importance to the mining geologist are a conviction that he has a type of technical training which no one else has, and a faith in its value; that, with all the uncertainties inherent in his science, he does know these uncertainties and weighs them in his decisions. He should possess a determination to come back time after time and with the willingness and the courage to assume the responsibility of trying again and again in the face of forbidding odds. He must have the ability and willingness to take the responsibility of making quick decisions involving substantial sums of money, with fragmental data only. Other qualities emphasized include aggressiveness, vision, scientific aptitude, business acumen, and sound judgement.

The tragedy may be that a man may possess all of these qualifications of a high grade mining geologist and may not be able to assume the high place to which they entitle him for one or both of two reasons, which are somewhat, although not exactly, alike. In the first place he must be able to get along with people; all sorts of people—his associates, his superiors, property owners, and all the rest. If he arouses antagonism or is irritated and disturbed too much by others and their rules, regulations, restrictions, and encroachments into his domain, then his effectiveness and ability to do creative work are impaired.

The other ability which he must have is that of being able to sell himself, his profession, and his ideas to the various sorts of people to whom they must be sold. Management listens to an eternal clamor as it is importuned to finance all sorts of projects, and the geologist must either bay with the pack or run the chance of having his projects relegated to a subordinate status. Unfortunately the embarking upon and prosecution of an exploration too often depend upon its manner of presentation and the salesmanship of the geologist rather than upon its geological merits. When the scientific ability and salesmanship of the geologist are both of a high order, the results can be happy, but if they are not, the results can be bad. A skillful and artistic draughtsman can dress up a most unlikely geological concept so as to give it a high degree of plausibility.

One would think that the consulting mining geologists, while their ranks include all extremes from the over-cautious and conservative to the over-optimistic and positive, on the whole should average high in ability to sell their services. The profession after a time learns what correction factor to apply to their appraisal of exploration and mining opportunities. Thus the enthusiastic reports of some are discounted and the conservative reports of others rated up.

I have presented some of the qualifications which a representative group of mining geologists who have been and are going through the mill, think members of their profession should have. Do you blame us when we do not get too excited over the details of the courses which a young geologist applying for a job has taken, or whether he is able to duplicate or even follow the mathematical analyses of the geophysicist? There are much more penetrating and significant questions regarding a man's ability to direct explorations as they are actually conducted.

YOUTH VS. EXPERIENCE.

"And it shall come to pass . . . that . . . your sons shall prophesy, your old men shall dream dreams, your young men shall see visions." I have mentioned in other connections differences between the youthful and the mature geologist. There are some who call upon the youth to guide us through our uncertainties. In recent years some of the outstanding geological faculties of the country have been very seriously handicapped by the retirement of their most valuable members within a short period of time. I saw one letter to alumni of such an institution telling of the efforts to rebuild their geological faculty. He said "young men have been sought and still younger men are being sought." Another, in sponsoring a young geologist for membership in a professional society, says he is one of those "bright youngsters whom we need to inject some new ideas into the doddering science of ore deposits." Both our own Society of Economic Geologists and the Geological Society of America now admit men to membership who twenty years ago might have been regarded as too immature professionally.

During the war the demands for geologists expanded and government and other employers were obliged to take on a host of youngsters, to assume responsibilities which hitherto had been delegated to more mature men. Some now regard the necessities of the emergency as having been the introduction to a permanent situation.

The limiting ages of usefulness of mining geologists should be a matter of individual consideration. Some men may be sufficiently seasoned by training to be highly useful before 30, and many are useful well into their seventies. There is room for the talents of both youth and maturity in larger organizations.

CONDITIONS OF EMPLOYMENT IN COMPANY GEOLOGICAL DEPARTMENTS.

There is a general feeling that mining companies must awaken to the fact that there are strong competitors for the geologists who are qualified to carry on explorations. There have been some caustic comments by leaders in our profession regarding the attitude of the companies toward their geologists. The kind of men they need are not obliged to regard it as a privilege to work for some of the large companies under existing conditions.

What are some of the conditions of employment as a mining geologist by the companies of the United States and Canada? In the first place, the U. S. Geological Survey, the Universities and the Petroleum industry can

successfully compete with the companies—and do—on a salary basis, both for young graduates and for more mature men. The list of those who have left mining companies and gone into these organizations and into other lines of work is impressive and not too heartening for the mining companies, considering the stakes which are involved in the maintenance of their ore reserves.

Living conditions are not too good for many mining geologists. In many camps they are much lower than those which technically trained men enjoy elsewhere. The camp is often remote, introducing obstacles toward a satisfactory family life. The children must leave home at an early age and at extra expense and sacrifice for their education. The search for ore is spreading farther and farther afield, and the geologist will have to become more and more of a globe trotter.

The geologist often reaches a dead-end after 20–25 years of service. He may become Chief Geologist with no place to go from there, he may resign and go into teaching or Survey work, he may leave geology and go into executive work, or he may go out on his own as a consultant. Some of my co-workers advise mining company work mainly as a step toward something else.

However there are compensations and remedies for at least a part of these causes of dissatisfaction. Without any doubt, mining company work has an appeal to different men according to their temperaments and ages. There is the opportunity which the younger geologists especially appreciate, that of travel and adventure.

Most of us in mining geology are in it because we like it better than we would like petroleum geology. Therefore we accept the financial sacrifice.

Many mining camps are small communities, and if the living restrictions of small communities are not too objectionable, there is the probability that salaries will go further and that the time saved in not having to travel every day to and from some distant office can be spent more pleasurably.

There are those to whom security has its appeal and for them University and Government Survey work has its attraction. A mining company can offset this by establishing retirement plans of its own. Some believe that the plan of compulsory retirement at any given age may work against the interests of the employer. As one has put it, there is no sense in allowing the calendar to rob us of the services of valuable men. At the present time, the conditions and policies of retirement and pensioning in the various mining companies vary widely.

The Universities have the Sabbatical leave as a device for keeping their faculty member up to date by allowing him periodic leaves of absence with pay. During this time he is supposed to engage in some activity which will increase his effectiveness as a teacher. Mining companies can well afford to give their geologists a similar opportunity. Ore deposits are highly individual phenomena and one of the valuable assets of mining geologists is a personal knowledge of a variety of them. Employers should see to it that they get this familiarity by periodically sending them out on visits to other districts.

Another way in which mining companies can compete with Universities and Government Surveys for geologists is to adopt a liberal publication policy. This is a definite asset to the ambitious employee. There are the old bugaboos, such as security, danger of litigation, or leakage of information regarding ore reserves, of stirring up governmental inquiry, etc., which are stressed by mining companies as reasons for refusal to permit publication. Some of these have been and may still be legitimate reasons on the part of some companies. However, the routine minded geologist is too prone to accept such "outs" for himself, "shrinking from the steps eventually involved in publication. On the contrary, the enthusiastic, inventive fellow naturally wishes to see the fruits of his work made known. A company policy against publication encourages the sluggard and penalizes and discourages the real producer." Those of us who enjoy this privilege of publication know that the preparation of a paper is a very effective way to clear up obscure points in our reasoning and bring fuzzy ideas in the background into sharper focus.

It goes without saying that it is not advocated that mining geologists join the ranks of those who like to see their names and pictures in the home town newspapers. It is advocated that mining geologists be allowed, or even urged, to publish papers which attain the standards necessary to compete for space in our journals of the highest rank.

Apparently quite a number of mining companies realize the importance of encouraging their men to attend technical meetings, in order to receive ideas. Those companies and men who receive but do not give in return can be regarded as professional parasites.

Now we come to what is a very touchy point, judging from the communications, both written and oral, which I have had with mining geologists. This is the place and relationships of the exploration geologist within the organization of which he is a part. There is little question as to where a staff geologist belongs whose duties are entirely local. His problems are a part of the problems of the local management and he should report to the local manager. But to whom should a man report who is responsible for planning and conducting explorations outside of any local manager's domain? Some companies solve the question one way and some another. Whatever way it is solved may involve considerable grief for the geologist.

The company may take the stand that since some local manager has geologists reporting to him locally, why not let this manager handle explorations in general? This is a cause of bitter comment. One geologist says that "Geologists who are unable to report to the top get kicked around a good deal." What is the true situation, and what is its cause? A local manager is usually harassed by day-to-day problems. Finding mines, on the other hand, is a matter of long-range policy both on the part of the geologist and the management. How can a long-range exploration policy be formulated and carried out under the supervision of some local manager? The geologist finds the degree of receptiveness toward his ideas fluctuating up and down with the manager's moods, in turn dependent upon the daily events around the mine. The manager may have taken a few courses in geology and may regard himself as entirely competent to conduct the geological work of his

company if more important things did not require his time and energy. He is the "practical" man whose job it is to keep a "theorist" within bounds. We all know how we must battle to be allowed to do certain things which seem so important to us, such as saving drill cores.

Our geological faculties can help remedy such situations. If, while they are trying to make geologists out of their geological students, they would impress upon the mining engineers who come in for a few fundamentals, what geology is, and the engineers' limitations in that the few courses they take no more equip them for modern exploration than would first aid courses equip them for practicing surgery, such conditions might be improved.

The alternative to having the geologist report locally is to have him report to some one higher in the organization. This is usually a happier set-up for the geologist. He is connected with the more remote and calmer atmosphere away from the immediate repercussions of the headaches of the local managements. Even reporting to an authority high in the organization is sometimes not too happy. If the higher-up does not have a background which enables him to appreciate the uncertainties connected with exploration, the geologist may find his time and energy taken up by endless reports, elementary explanations for his boss's benefit, and his own sales arguments to do this or do that. Or his superior in some instances may be an official in the main office who knows enough geology to appreciate these problems so well that he must needs keep in trim by sticking his oar in occasionally and running the exploration himself. A friend was once field geologist in a drilling campaign and was given a certain amount of latitude in spotting the holes. There was a very heavy drill on the job, the hole locations were on a steep side hill, and the weather was stifling hot and humid. On the completion of a hole, he moved the drill *up* the slope for the next hole. The drill crew tugged and sweated and by a series of switch-back operations got the drill in place. Just then a letter came from the main office saying to spot the next hole *down* the hill. With a heavy heart the geologist went out to the drill and told the crew that he had made a mistake, the drill would have to be moved down hill from the hole just finished. They tore down again and started moving down hill, this time with more speed because they at least were on a down grade and in order to take advantage of not having the sun shining on them they worked right through into the night. But in the meantime the geologist, in order to explain the time lost in moving, had written a letter to his head office telling what had happened and why. Back came a telegram saying that he was right, drill the hole where he had originally planned. This instance of main-office geology is a petty one. I know of others which are not petty. I know of well-conceived explorations which were abandoned at a promising stage because the field men, entirely competent in their area, were hamstrung by head-office interference.

Why is it that mining geologists find themselves in such unhappy environments? I think it is a hold-over from the days when mines outcropped, when anyone who was told that iron was red, copper green and gold yellow had a chance to make a discovery. Even since the going has become tougher, luck still plays a part, and everyone thinks his luck may be as good as the

geologist's, and accordingly feels competent to interject his advice. After the geologist's data and ideas "click" and a discovery is made, the distinction between discovery and development tends to become fuzzy and everything may seem so simple that all hands often honestly believe that "they knew it all the time." As one non-technical rising executive said, "After all, geology is only common sense!"

In the search for metal mines there still is a dwindling remnant of the "where she is, there she is, boys, let's go" spirit, and the boys with the "nose for ore" still dash around with their brief cases, making snap decisions for companies whose primary reserves are still big enough to enable them to indulge in such luxuries.

When petroleum geology conclusively demonstrated that it could outplay Lady Luck, then the lot of the petroleum geologist became happier. Some of the oil companies have geologists as officers in charge of exploration, even with the rank of vice president. As a result, the young man going into petroleum geology has a better chance of having his efforts appreciated because they are understood.

In any event a mining company is just using common business sense if it tries to keep up the morale of any part of its organization and not let it give up the battle, mark time, or slump down into an attitude of "what's the use." One good way to make its exploration geology more effective is to put it under a higher-up officer who, if not a geologist, at least appreciates the problems of the geologist and is sympathetic with his efforts to get explorations onto a higher plane than perhaps can be easily appreciated by the local manager struggling with his daily problems.

ATTITUDE OF MINING COMPANIES TOWARD EXPLORATION.

The qualifications which make a geologist a good explorer have been mentioned. But what makes a *mining company* a good explorer? To some extent there must be individuals in the group that makes the policies, who have the same personal qualities which the geologist should have. Executives are chosen for various reasons, among which may or may not be the qualities which make for a good explorer; chosen, perhaps, even for qualities which do not go too well with those of a successful explorer. This may have its compensation so far as the good of the industry goes; it is the old law of survival of the fittest, and such companies will automatically pass out of the picture. Exploration is no game for the conservatively minded; they had better go into banking or groceries. Large companies have certain advantages; they have capital and organization. On the other hand, they may expect too much. If they have been mining one of the big ore bodies of the world, the prospect which offers only a million tons of ore looks uninviting. The varying attitudes of mining companies toward exploration depend upon their differences in magnitude of ore reserves, their cash position, and the vision and temperament of their officers.

There must be persistence on the part of the mining company in exploration as well as on the part of its geologist. We all know of areas where

companies abandoned explorations when they had encouragement to continue. We cannot waste much sympathy on them when other explorers come along, deepen their drill holes, or extend their drifts, and make a strike. If their geologist recommended continuing the exploration, it would seem to serve them right to have the next one make the strike, thus vindicating their own geologist. One of my correspondents says that if a geologist must sell his company on exploration nowadays, it is time for him to pick a new company.

In some cases an exploration fails because too much is attempted with a too limited appropriation. The exploration of the several objectives or hypotheses in a logical rational sequence is impossible, and the geologist, perforce, must risk bungling things by trying to make one drill hole or crosscut do the work which properly requires several. After a few of these fail, discouragement sets in and the exploration is dropped without conclusive results having been obtained.

Geologists should not hesitate to make it clear that exploration will probably require increasing time for comprehensive studies, increasing money to spend, and a fair share of luck, to hope for success. Furthermore, they might admit that in many cases their ability to find ore will continue to outstrip their knowledge as to why it is where it is.

There would seem to be a certain period in the life of companies which have been fortunate enough to mine out some of the large ore bodies of the world, when, if other conditions were right, there would be the optimum opportunity for effective exploration. In the early stages they are satisfied; they are the anointed, there is plenty of ore, why worry about a distant future which may take care of itself.

In the declining days when the ore bodies which were to last forever are about done for and the pinch for ore becomes extreme, there is the feeling of frantic pressure arising with the sickening realization that this is the end. Then the question, what to do? The calm, detached mood which is necessary for the conception and execution of a rational exploration program is difficult to maintain under such circumstances. There is likely to be a vacillating swinging from one extreme to another in the attitude toward exploration.

But somewhere in between the two extreme periods in company history just described, there is the opportunity for orderly, planned exploration. The realization of the inevitable is just dawning and there is still a long life of earnings ahead. Far-seeing officials feel the incentive, while there still is time, to embark upon a long-range program of exploration intended to perpetuate their company as a mining organization. I believe many of you can classify some major mining companies into these three groups.

Apparently there is still a substantial remnant left of the company attitude that exploration is a sort of luxury to be indulged in only when times are good, and that it is one of the first activities to be curtailed when the cycle takes a downturn. Fortunate is the company with officials who realize that regardless of temporary changes in business conditions, swinging up and down from pessimism to optimism and back, their inescapable obligation is to maintain ore reserves; that the very existence of their company depends upon exploration; that this obligation must be accepted and that its financing

should be anticipated and provided for in advance, so that its implementation can be independent of temporary needs and conditions. It can therefore be carried on most advantageously not in periods of prosperity when costs are high and men hard to get, but on the contrary, in periods of depression, when costs are low and men are plentiful.

GENERAL PHILOSOPHY OF EXPLORATION.

It is frequently said that the present trend is to gather the ore deposits of the world into bigger and fewer hands. This is probably true, in spite of the fact that smaller companies may be better explorers. The lower grade deposits which will be the source of metals in the future will of necessity have to be large during the time they are competing with the remaining high-grade deposits. The smaller companies however may get an extended lease on life by going into exploration partnerships.

The feeling has been expressed that the rate of exploration must be increased. This means larger exploration budgets, and the mining geologist must assume the increased responsibility which will result.

The matter of estimates of exploration cost deserves mention. We fully understand the desire of a company to know how much a project will cost. But planning an exploration is vastly different from planning a new recreation hall. The course of an exploration depends usually upon facts which emerge as the work advances from stage to stage. The geologist feels his way along, often being able to plan his work no further ahead than to decide upon the next step. As one man summarized this phase of his successful career, "In every case we proceeded with the project on the factual evidence that developed as the venture progressed." Some one high in an exploring organization must have the geological background or the broad personal understanding to enable him to appreciate why a property like San Manuel can jump in a short time into the millions-of-dollars exploration class from the $25,000 or $50,000, or whatever it was originally. On the other hand, something based upon a long shot geological hunch can be equally suddenly deflated.

An additional word might be said here about the subject of persistence and faith. A recent author giving the history of a certain discovery said it was one of persistence and faith, that with these qualities and without geology many mines of the past have been developed, and without them geology would accomplish little. This is true, but it should be said equally emphatically that many have gone broke on mere persistence and faith, without intelligent direction.

The part luck plays in exploration is unfortunately large enough to play havoc with the geologist, but what we call luck is simply the effect of all of the unknowns and unpredictables which lie hidden in the geology of an exploration. They lurk there and jump out unexpectedly to wreck our carefully conceived ideas. Then we say luck is against us. Occasionally, however, they emerge equally unexpectedly to help us out. In this case, luck is with us. It thus can work out that a poorly conceived plan geologically may pan out well, and a well conceived one may utterly fail.

Since explorations are now based upon more and more obscure indications of possible ore, it is desirable that more time and money be spent upon the preliminary studies before expensive drilling and underground work are undertaken. Areal studies by the Federal and State Surveys are especially appropriate at this stage because as soon as any activities are started by a private company the usual handicaps exacted by property owners from whom exploring options must be obtained, may force that company into premature activities. Such handicaps are those imposed by minimum work and labor clauses, option payments, etc.

Also with explorations based upon more obscure ore indications, the cost per unit of exploration has increased. Seldom do we now find opportunities lying around upon which we can spend a mere $25,000 for some trenching or drilling. One may now easily spend $100,000 and still not have an answer. This again places greater responsibility upon the geologist.

The working methods of the company geologist are changing. Formerly he raced around the country looking at prospects. Now he does a lot of library research, trying to interpret the results of public surveys in terms of exploration possibilities, and to develop hitherto unrealized opportunities for his company. However, it is still a good idea to get around and look at things in the field. It lets people know your company is alive and even though preliminary information may indicate that the property which furnishes the immediate reason for paying some area a visit is unattractive, still something else really worth while may come to attention as a result of the visit. Examples of this are common.

Fortunate are the geologists who are with a company large enough so that their field geologists are not obliged to work alone. The lone wolf deserves sympathy. In geology two heads together are better than two heads separate. There is the stimulation of the exchange of ideas, the sharing of responsibility, the reassurance and confidence of having someone on your side when you are being given the rush act by promoters, etc. Then there is the likelihood that no one man can any longer have the education and training to size up adequately one field occurrence after another. In a broader sense the opportunities for the most important contributions to the fundamentals of ore deposition will probably be greater, not only for groups of geologists as opposed to individuals, but for those groups which have opportunity for consultation with chemists and physicists.

The rate at which a given exploration is carried out is important. There is the matter of overhead, of getting maximum information before option payments become due, and other factors which make it desirable to push things along. On the other hand there is such a thing as getting indigestion from too much and too early information. How many times have we wished that we could defer setting Hole No. 6 until Hole No. 5 was completed. But we have two drills instead of one, and it would cost a lot to lay up one drill awaiting the completion of a hole, so we must set the new hole and take a longer chance.

And now we come to another matter which I believe deserves serious consideration. By ancient and accepted custom there is a time and place for

field work and a time and place for laboratory work. One maps and collects specimens in the field, and perhaps months later takes them into the laboratory for study. Thin sections are then made, and also, in recent decades, polished sections of ore. The field and laboratory studies are kept pretty rigorously separated. The equipment in the larger University and other laboratories has become more and more precise and elaborate. The students become accustomed to studying ready-made thin sections and highly polished, non-relief ore sections, mounted in bakelite, both prepared by expert laboratory technicians. I have the greatest admiration for such equipment and preparations. I do believe, however, that it is a great mistake for the Universities not to make it clear to the students what can be done by hand, or at most, with a single high-speed wheel for final polishing. I have seen graduates of Universities having this fine equipment who had never themselves made a thin section nor a polished section by hand. As a matter of fact, some did not know that this could be done. I believe that they should be able to make such preparations. Thin sections can be made with simple equipment the equal of those ordinarily made commercially. Hand-made polished sections are not mounted in bakelite, and the polishing is not of the non-relief type, but they will serve most purposes, such as the study of mineral identification and relationships, supergene enrichment, grain size and other features.

If an exploration seriously involves a study of rock alteration it may even be decidedly advantageous to be able to make and study thin sections on the spot. In an exploration which we are now conducting we can make a good thin section of a piece of drill core without any machinery and be studying it under the microscope sometimes within two hours of the time it is pulled from the hole. Character of rock alteration is a factor involved, and without such prompt action in the field we would be rather at a loss. A procedure which grew up in the early days when parties were sent out into the field in remote areas for a short summer field season, is neither necessary nor desirable when an exploration with diamond drills running day and night needs petrographic data, not next fall but right now.

I strongly recommend that our geological departments in the Universities do what they can to abolish the ancient idea of there being such a great time and space gap between field and laboratory work, and that they devise improvements and simplifications of section preparation which will be usable in the field, and teach them to their students as a part of the laboratory work in economic geology.

ETHICS.

Mining geologists encounter situations where the line between what is strictly ethical and what is not is somewhat vague, others where it is clear cut. A geologist working for a reputable mining organization probably is not confronted by as many of these situations as is the consulting geologist. We recognize two kinds of unethical practice, one against society and the other against our science. There are gross violations such as the abuses which

may follow the acceptance of shares in an enterprise as compensation for professional work. Sometimes this may also include an option on additional stock for a certain period. Chosen excerpts of the geologist's report are printed by a compliant press, the stock goes up and the geologist may then dispose of his stock and pocket the returns regardless of how the exploration may subsequently turn out. If it should turn out well, however, he has an option on additional stock. There is no question as to the ethics of situations of that sort. But there are imperceptible gradations into the ordinary case of the geologist employed by our largest companies, buying the stock of that company. Is it unethical to do so? In any event, if a geologist has an interest in a property on which he reports, it should be known, not concealed. Then there are borderline cases where a client wants a yes or no answer, and if it is yes, he doesn't want to know all of the qualifications and uncertainties involved in the exploration. Some geologists cannot write such a report, others of a more optimistic nature can and do write them. Reports do get around and are copied, and such a one-sided report may be used years afterward for promotional purposes of a type which the writer had not contemplated.

Another type of unethical practice involves temporizing with the highest principles of our science. A geologist may sometimes shade the emphasis here or there for certain purposes, perhaps not even enough to be caught up by other geologists. But he himself knows what he has done. I know of one geologist who was accused of always having the actual evidence supporting his contentions unavailable in some caved-in mine opening.

PUBLICATIONS.

The technical press of mining geology ranges in dignity all the way from promotional brokers' sheets up to our top-notch mining and geological journals. From the bottom of the list, out-and-out propaganda is expected. The booming of penny stocks and properties is accepted as a matter of course. Occasionally geologists receive their share of glory from such sources. One example was cited where a geologist was credited with a great success; the first hole he spotted hit the "ore formation." But, any hole within miles would have encountered the same formation.

Coming up the scale there does not seem to be very much concealed propaganda in our better journals, although occasionally those who are better acquainted with a mining district than the general run of readers may suspect a hidden axe being ground under what purports to be an objective, scientific account.

There is also a type of propaganda which does get by, but it is pretty generally recognized as such. When one of our brethren who is commonly known as having a connection with some property whose product is subject to a tariff barrier somewhere, discourses upon the iniquity of barriers in restraint of trade, and expresses sorrow that all mankind cannot have free access to certain products, we listen solemnly. No one is fooling anyone. Similarly when the owner of some hole in the ground which would not make

a mine under any system requiring free competition, discourses upon the need of subsidies for the patriotic purpose of building up a stock pile, or for any other patriotic purpose, we listen just as solemnly. Such propaganda is accepted by all, those who promote it as well as those who listen to it, as being just what it is, and we don't blame the editors for publishing it without its label. It is refreshing, nevertheless, to hear the president of a large U. S. iron company come out frankly and admit that when their mining interests were solely in the Lake Superior district he did not think the St. Lawrence waterway would be a good thing, but that since they have become interested in certain foreign properties he has changed his mind.

The editors of our journals also have a responsibility as to the type of papers accepted for publication. Without going into the situation here I may say that I have received two comments which express the opposite extremes of opinion. One is concerned over the half-baked papers, those which confuse what is plausible with what is proof, and which, instead of advancing, back away from a position already established and head off again toward some old dead end. Another takes a stand which might be just the opposite. He wants to allow the unorthodox a greater opportunity to get a hearing. He is concerned because the heavy hand of dogmatism is having too much to say as to what gets printed!

U. S. GEOLOGICAL SURVEY.

It is believed that the Survey will play an important part in the vital search for new deposits and districts, and the general feeling is one of cordiality toward them. My own attitude toward the activities of the Survey party in the Michigan Copper District is that I have nothing to lose and everything to gain. If they turn up some new principle which will aid in the search for new deposits, I will have new explorations to direct in trying them out. If on the other hand they find that they cannot suggest improvements in the way we explore, then I can point with satisfaction to the work of the geologists of my group. I will be able to say that so far no one has found that we have overlooked anything vital. So I should think the attitude would be in other camps where the Survey is working. There is a great variation in degree of cooperation given the Survey by the mining companies. My own company gives them access to practically everything. On the other hand, in other districts they have occasionally not only been refused access to new information by the mining companies, but have been forbidden to republish material already printed and available to the public.

During the war there were some extraordinary demands which the Survey had to meet. Besides those dealing with Military Geology was the demand for the same kind of services as they had been giving, with two new qualifications, namely, that these services be performed at a greatly increased rate, and that the Survey be more practical. This meant a great expansion in personnel. It was inevitable that men less mature and less experienced had to be taken on and that the older experienced supervisors had to be spread out pretty thin. For many years we had heard the critcism made of the

Survey, especially by mining men, that it was not "practical." Well, during the war the demand came that they be practical; that the war requirements were for results right now. The Survey hastened to reorganize to meet these demands and now that the war is over it has had to adapt itself to the new conditions. Therefore, the Survey, as it is now constituted, inherits a war-time, emergency organization and must continue to fight the possibility of lowering of standards and of a shifting of these standards away from a truly scientific basis because of the sudden expansion and the demand for "practical" results. If the danger is recognized, and it undoubtedly is, the Survey should come through in a healthy condition.

Two problems of long standing whose solution would render even more cordial the prevailing friendly relations between mining company geologists and the Survey are those of speeding up publication of Survey studies and the working out of some way of giving adequate recognition to the company geologists who, by making available their ideas and information, thereby contribute substantially to publications printed under the authorship of the Survey geologists.

In any event, there seems to be general agreement that the U. S. Survey, and the same thing applies also to State Surveys, can be of great assistance to the mining industry in the search for new ore, especially if they stick to the broader and more scientific geological investigations and do not encroach upon fields which are more properly those of the mining companies.

U. S. BUREAU OF MINES

This organization has encountered the same political pressure, over-expansion and the effort to be "practical."

So far as I can make out from the comments which I have received, there is the feeling that during the war emergencies the U. S. Bureau of Mines took over some parts of field exploration which normally belong to the mining geologists, the U. S. Geological Survey, and the mining companies. The war is over and there is now plenty of opportunity for all of us to again do the things for which we are best qualified.

THE LAW, MINING, TAXATION, ETC.

There is a general agreement that there are laws, both federal and state, existing and contemplated, the modification of which would help exploration. The comment is heard that on account of the high taxation, even though one may win, there is no great incentive to go after new ore deposits. On the other hand it is apparent that there is no lack of capital when a big ore body like San Manuel is to be financed. Even insurance companies have recently, and perhaps rashly, made loans on speculative mining developments.

Another fear concerns future uncertainties in tax laws. In other words, things are not so bad that some one could not make them worse.

In all fairness, however, it may be said that some states have very favorable laws which provide incentive toward exploration.

One thing which hangs over the mining industry of the United States like a dark cloud is the fear of the present political trends toward nationalization of mineral resources. The present mining laws are bad enough, but at least they provide a means whereby those who have the enterprise to take the risks necessary to discover and develop a new ore deposit in the public domain can obtain possession of the land. The Department of the Interior in recent years has shown a tendency to advocate that the government retain control of all mineral lands remaining in the public domain. Under such conditions a mining company would lease, or pay a royalty on production, if it wished to mine, instead of going through the present procedure which ultimately gives it ownership of the land. A bill providing for such leasing, to be administered by the Department of the Interior, is said to have been drawn up by Oscar M. Chapman, Acting Secretary of the Interior, and forwarded under date of March 3, 1947 to the Hon. Richard J. Welch, Chairman, Committee on Public Lands, House of Representatives, in the 80th Congress.

Of course the mining industry is the poor relation on the doorstep because of the small vote pull which it has, and the lack of a public enlightening as to its needs. It is hoped that the inevitable awakening after the party is over will come before it is too late; that while we have established and supported mining industries in various countries of this our One World, there will still be enough breath left in our domestic industry to enable it to be revived.

I should state here that while Canadian geologists, as the second largest national group in our Society, have contributed in part to the general features of this discussion, I have decided not to comment specifically on the Surveys, Bureaus and laws of any country other than the United States. To do so might very well be resented.

LOCAL PEOPLE AND PROBLEMS.

When a company comes into an old district to try to revive it there seems to be an attitude on the part of the local people of "glad you came in boys, hope you succeed," but in the meantime all of the petty grafters get in their licks. They stake all around you and over you. You faithfully perform location and assessment work and you know that they do neither. The geologist of one of the large companies told me that they would like to get into some of the dormant districts of the country and study them with the care that would be necessary, with the idea of spending some real money if the study pointed to likely looking objectives. To justify any such procedure, however, they naturally feel that they should control some land to start with. But when they go to the owners with their story they run up against all the old complications with which you are familiar. The owners want down payments or quarterly payments or other kinds of payments; anything just so there are payments. They want minimum work requirements and all the rest of it. What you, the explorer, want first is to have time to study the district. Maybe you will find the objectives you hope for and maybe you will not. If you do, you are willing to spend money, but

you want a chance to find out where, and you want to spend it on the property itself. But no, that is not the way it is to be. So, according to our friend, they just give up. Often the desirable land gets so tangled up in estate settlements that no one then wants to try to get it.

CONCLUSION.

Regardless of the imposing lists of metal mine discoveries in recent years, we must accept it as a probability that the difficulty of finding mines will outstrip any expectable development of skill in exploring. As the pinch of scarcity is felt and as discovery wanes, metal prices will increase, having the double effect of allowing lower grades of ore to be worked and of stimulating exploration. Exploration is with us to stay and the mining geologist is going to have an increasingly responsible position in the situation. The purpose of this talk has been to indicate the various ways in which mining geologists who are spending their lives on these problems think their efforts can be made more productive. This talk has emphasized causes of discontent because its purpose is to indicate those features whose correction can make exploration more effective. You have heard some of the shortcomings of the geologists themselves, of the educators, the mining companies, our technical publications, the Federal Survey and Bureau of Mines, and the property owners. It is said that the recognition of a problem is the first step in its solution, and I hope that this cataloguing of the vulnerable spots in exploration will at least crystallize our ideas as to where to spread the gospel of how to make our work more productive. We are vitally interested in all of this. We have the confidence of, and carry conviction with, those men who can approve the exploration of new objectives of interest which we recommend. We are in mining geology because we like it and if I were to pick out any one reason as to why we like it, it would be because we do have a privilege and advantage which most other geologists do not have, namely, we know that our ideas will not be put away to gather dust, but that we will have the excitement and satisfaction of having them tried out promptly in the field.

CALUMET AND HECLA CONSOLIDATED COPPER CO.,
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April 27, 1949.

PETROGRAPHIC ANALYSIS OF COAL BY THE PARTICLE COUNT METHOD.[1]

BRYAN C. PARKS.

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[1] Published with the permission of the Chief, Illinois State Geological Survey.

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ABSTRACT.

Quantitative determinations were made of the banded ingredient composition of a number of domestic stoker coals prepared for combustion tests from large lot samples of small-size coal procured at 15 Illinois coal mines.

The determinations were made by identifying and counting the discrete coal particles in selected samples using the petrographic technique which is commonly used to assay performance in ore dressing operations.

A standard procedure for the analysis was developed which included close control of all steps in selecting the sample, crushing to free coal components into discrete particles, and size classifying the particles by mechanical screening. Strict criteria were adopted for identifying the coal particles.

The results of the petrographic analyses which were of special interest in connection with the combustion tests concerned the effect of coal cleaning processes upon the proportion of banded ingredients. An increase in vitrain content of the cleaned coal was usually noted but concentration of this ingredient was never of considerable amount. The analyses also showed there was no great concentration of vitrain in the lots of small-size coal secured from the mines. Previously it had been thought that vitrain by virtue of its friable nature constituted a major proportion of the "screenings" produced in coal mining and preparation.

During the course of the work certain incidental investigations were carried on concerning the effect of differences in hardness of the banded ingredients on size distribution when more or less "pure" ingredients were crushed under controlled conditions. The variation in specific gravity of the banded ingredients and the effect of this variable property in separating or concentrating coal ingredients by use of heavy liquid media was investigated. The paper discusses reliability of this method of petrographic analysis of coal and reports certain experiments made to determine degree of accuracy achieved.

SUMMARY.

PETROGRAPHIC analysis of coal provides information concerning its ingredient composition in terms of vitrain, clarain, durain, fusain, and mineral matter. Lumps and columns of coal are analyzed by making profile or vertical measurements normal to the banding of polished surfaces. It is more difficult to analyze broken coal but it can be done by using conventional petrographic methods of rock analysis or by particle count, using methods employed in ore preparation and in other fields. The results of analysis, by particle count, of a group of small size broken coals used in stoker tests are herein reported.

The coals, which were generally screenings as obtained from the mines, were sized to ½-inch by 8-mesh for the combustion tests (one exception).

A series of three combustion tests was generally made on each coal. These were on the (1) unwashed coal, (2) a washed coal prepared by tabling in a normal manner, and (3) a washed coal with a mineral matter content lower than commercially reasonable.

For the particle count method, the samples were crushed to pass an 8-mesh screen. The demarcation between vitrain and microvitrain, the latter a component of clarain, was regarded as 1/10-inch.

Exploratory analyses made by the Illinois Geological Survey about 1936 indicated that coal preparation processes caused material changes in the proportions of the banded ingredients in the coals tested, up to the point where as much as one-half to two-thirds of some coal samples consisted of vitrain. It was thought that such high concentrations of vitrain, or even much smaller concentrations, would have pronounced effects upon the combustion characteristics of the coal when used in stokers. The preparation in the present tests was expected to cause considerable concentration of the ingredients. The maximum concentration of vitrain, however, was only about 30 percent. The vitrain content in several of the washed coals did not exceed 10 percent. In one case it was as low as 2 percent. These results were unexpected, but were obtained after improved analytical technique had been developed as the result of investigation along four lines of inquiry:

1. As one of the difficulties of analysis and a possible source of error lay in determining the ingredient composition of the very fine sizes of coal, it was desirable to develop a satisfactory technique which would reduce to a minimum the quantity of such a size. A method involving the crushing of the coal through rolls was finally adopted.

2. A further source of error consisted in the unknown extent to which microvitrain, which is one of the common components of clarain, contributed to the material classified as vitrain in the analyses, that is to the "analytical vitrain." The yield of analytical vitrain from coal containing no vitrain bands (thickness 1/10-inch or more) was therefore studied and found to be less than 6.9 percent of samples tested and to be limited chiefly to the very small screen sizes, generally smaller than 28-mesh. Reduction of the amount of this very fine material by careful crushing lessened the importance of this factor of error.

3. Although the amount of fine coal could be considerably reduced by careful handling, an important quantity remained and a knowledge of its character was essential to accurate measurement. Also its very fine size made quantitative measurement by counting disproportionately laborious. Systematic investigation of size distribution of the banded ingredients in crushed coal revealed that definite relations existed between size distribution of each of the banded ingredients and that of the sample as a whole. Accordingly, by the use of a special curve of size distribution, it was found possible to estimate closely the quantity of each ingredient present in the small screen sizes, once such quantities were determined for three or four of the larger screen sizes. Thus labor, time used, and the probability of error were greatly reduced.

4. The amount of segregation caused in cleaning the coals used in the stoker tests was investigated. Experiments revealed inconsistency in the behavior of the broken coal in float-and-sink liquids, showing particularly that vitrain did not systematically concentrate in the low-gravity fractions in spite of the fact that the lightest individual fraction of the coal tended to be vitrain. Concentration appeared to be significant only when the gravity of the separation fluid approached the minimum specific gravity of the vitrain. These tests provided a reasonable explanation for the low vitrain concentration reported in the particular stoker coals analyzed.

INTRODUCTION.

Plan of the Report.—This report describes a method of physical (petrographic) analysis of broken coal in terms of the banded ingredients, particularly vitrain and clarain, applied to a group of Illinois coals used in combustion tests in an underfeed domestic-type stoker attached to a hot-water boiler.[2] The report also gives the petrographic analyses of the coals. It describes additional tests, to establish the validity of certain details of the analytical procedure and to explore the effectiveness of the cleaning practices used in segregating the ingredients into the various size and gravity fractions, as applied to these particular coal samples. No effort was made to explore the possibilities of producing from Illinois coal prepared coal with a high single-ingredient content. Petrographic analysis of any coal is possible by using the method here described.

Coal Ingredients.—The banded ingredients of coal—vitrain, clarain, durain, fusain, and mineral matter—have been described in earlier Survey publications.[3] The criteria of banded ingredient identification are given in Table 1.

Vitrain bands (Figs. 1 and 2) as thick as three inches have been observed in Illinois coal; thinner bands occur. Those of microscopic size are referred to as microvitrain, which is a common component of most clarain. Clarain is the major ingredient of Illinois coal, commonly making up 70 percent or more of the beds. Its prime diagnostic characteristic is a distinctly laminated structure which, in the brighter clarain, produces a silky luster. The brightness and silkiness of luster of clarain increase with the amount of microvitrain present.

No standard of band width has been adopted for differentiating vitrain and microvitrain. Stopes,[4] working with British coals, suggested that vitrain occurs in layers commonly ranging from 2 mm to 8 mm thick. Cady [5] at first suggested that for Illinois coals the minimum thickness of vitrain should

[2] Helfinstine, Roy J., and Boley, Charles C., Correlation of domestic stoker combustion with laboratory tests and types of fuels. II. Combustion tests and preparation studies of representative Illinois Coals: Illinois Geol. Survey Rept. Inv. 120, 1946.

[3] Cady, Gilbert H., Nomenclature of the megascopic description of Illinois coal: Illinois Geol. Survey Circ. 46, 1939.

[4] Stopes, Marie C., On the four visible ingredients in banded bituminous coals: Studies in the composition of coal: Royal Soc. London Proc., vol. 40, p. 470, 1919.

[5] Cady, Gilbert H., The physical constitution of Illinois coal and its significance in regard to utilization: Illinois Mining Inst. Proc., p. 6, 1933.

TABLE 1.

CLASSIFICATION AND DESCRIPTION OF THE BANDED INGREDIENTS.

Banded ingredients	Classification of banding	Range of thicknesses	Distinguishing criteria for identification of the banded ingredients		
			Characteristics of bed-coal and lumps	Characteristics of small particles—1/10" dimension	Characteristics of polished surfaces
Vitrain	Coarse bands Fine bands Micro bands	+1/10" (+2 mm) 1/10" to 1/50" (2 to 0.5 mm) −1/50" (−0.5 mm)	Bands jet, glossy, black; smooth textured; conchoidal fractures; often prominent vertical fractures filled with mineral matter in the thicker layers, brittle.	Irregular particles tending to be lense shaped, conchoidal fracture, thin edges; black to grayish; brilliant luster, smooth textured. At low magnification thin edges often show orange colored translucency, also the entire particles in very fine sizes.	Jet to grayish black, homogeneous texture, brilliant luster, high reflectance.
Clarain	Fine banded Micro banded	1/10" to 1/50" (2 to 0.5 mm) −1/50" (−0.5 mm)	Bright to grayish, streaked or silky lustered, fracture uneven and conchoidal, harder than vitrain but sometimes brittle.	Irregular shaped particles, less lenticular than vitrain but some showing conchoidal fracture, streaked appearance characteristic of all particles larger than 1/50", smaller particles show only a varying proportion of dull coal attached to vitreous coal.	Bright, streaked and silky lustered, sometimes dullish gray.
Durain	Coarse bands Fine bands	+1/10" (+2 mm) −1/10" (−2 mm)	Dull grayish, even textured, mat surface, grainy fracture, hard.	Particles tend to be platy shaped with fracture planes nearly at right angles in larger particles, grainy surface, dull gray, small particles very irregular and grainy, often with spores and rodlets imbedded in surface.	Dull gray, even mat textured.
Fusain	Coarse bands and lenses Fine bands	+1/10" (+2 mm) −1/10" (−2 mm)	Jet black to grayish black, sometimes brilliant; often has loose splintery appearance; usually very soft but sometimes firmly cemented with mineral matter.	Needle and platy shaped particles jet black, grayish, and sometimes brilliant; surface punctate showing evidence of cellular structure; usually very soft and powdery but sometimes hard and brittle.	Dark gray, porous.

be established as 1/16-inch but later was of the opinion that there was practical justification in placing the limit at about 0.1-inch or approximately 2 mm.[6] McCabe[7] and others, measuring columnar sections, limited the measurement of vitrain to bands plus 0.5 mm or about 0.02-inch thick. In this investigation the minimum width of vitrain bands was regarded as 0.1-inch in accordance with the tentative definition of Cady in 1938, although megascopic identification of the material is possible to about the minimum of 0.02-inch. The modification of the analytical values on the basis of a minimum thickness 0.02-inch is considered in a later part of this report.

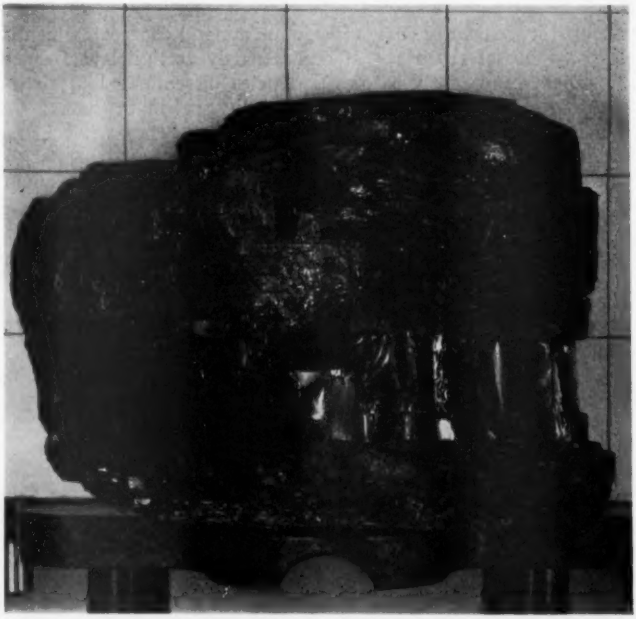


FIG. 1. A lump of Indiana bituminous coal showing clarain above, a thick band of vitrain (glossy), followed by fusain, with clarain at the bottom. Background shows two-inch squares.

The bright luster of clarain diminishes with decrease in the content of microvitrain, and it passes more or less imperceptibly into a dull grayish coal, known as *durain,* with a mat or lusterless surface. There is megascopically no clear distinction between clarain and durain; durain, however, is

[6] Cady, Gilbert H., Modern concepts of the physical constitution of coal: Jour. Geology, vol. 50, no. 4, pp. 337–356, May–June, 1942.

[7] McCabe, L. C., Concentration of the banded ingredients of Illinois coals by screen sizing and washing: A.I.M.E., Tech. Paper No. 684, 1936.

characterized microscopically by the presence of opaque matter and a general absence of microvitrain. Cannel coal is regarded as a variety of durain in which a large part of the coal consists of plant spores. Certain cannel-like coals of very fine texture and silky luster, however, are composed predominately of extremely thin, closely packed sheets of microvitrain. On the whole, durain and cannel coal are very minor constituents of Illinois coals. Bands of coal of a grayish tint and dull luster, suspected of being durain, commonly contain much mineral matter. Durain (Fig. 3) in Illinois coals is difficult to identify except in thin sections because of the similarity of bands of durain and layers of bony coal or other coal with a high mineral matter content.

The fourth ingredient of coal is fusain, or mineral charcoal, which has the general appearance of charcoal. It occurs partly as thin layers among the other ingredients and partly as small particles disseminated in clarain and durain. Most of the fusain that was originally present in the coal used in the stoker tests was eliminated during preparation; hence this ingredient is unimportant in these investigations.

Because the properties of the ingredients differ, the relative quantity of the individual ingredients composing a coal may be of significance in its utilization. Investigation of this possibility was one of the objectives of a series of stoker-boiler tests on a variety of Illinois coals, so prepared that selective segregation of the ingredients seemed possible.

Acknowledgments.—The author gratefully acknowledges the help of H. L. Smith, formerly Assistant Geologist of the Coal Division of the Illinois Geological Survey, who assisted in the preparation of many of the samples for microscopic analysis. C. C. Boley, formerly Mining Engineer, and R. J. Helfinstine, Mechanical Engineer, of the Coal Division staff, have given generously of their time and thought in discussions of many problems. G. H. Cady, Senior Geologist and Head of the Coal Division, supervised the work and gave generous assistance and advice in the preparation of the report.

PETROGRAPHIC ANALYSIS OF BED COAL AND OF BROKEN COAL.

Analysis of Bed Coal by Profile Measurement.

Lumps or bed-columns of coal or diamond-drill cores of coal beds can be fairly easily analyzed in terms of the banded ingredients by visual inspection of polished surfaces. The character and width of individual bands are recorded serially by profile measurement normal to the bedding. The method is similar to that used in making a record of strata penetrated in drilling, but on a much smaller scale.

This study did not include an investigation of the amount of banded ingredients present in the bed coal from which the samples were derived; however, this had been done previously for coal beds in several parts of the State [8] (Table 2).

[8] McCabe, L. C., Mitchell, D. R., and Cady, G. H., Banded ingredients of No. 6 coal and their heating values as related to washability characteristics: Illinois Geol. Survey Rept. Inv. 34, p. 14, table 2, 1934.

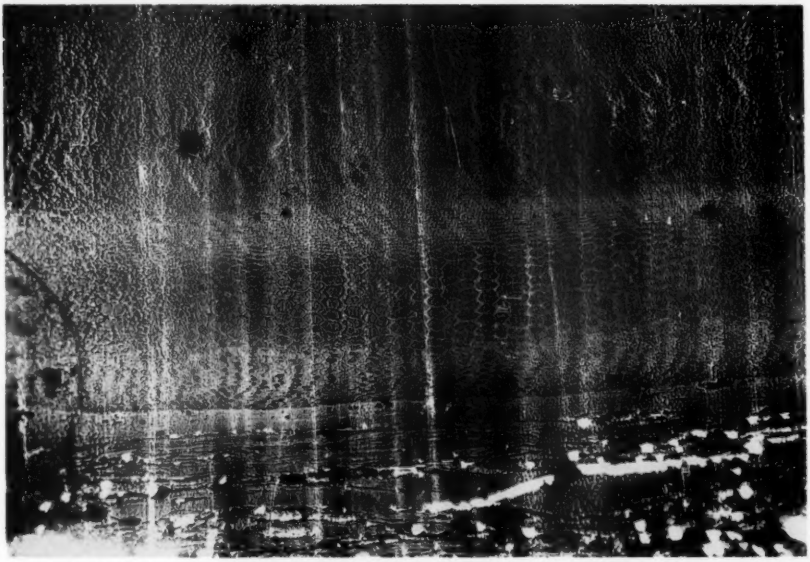


FIG. 2. Thin section of coal with vitrain showing cell structure. (Lower part is clarain.) No. 6 coal, Winkle mine, Perry Co., Ill.

FIG. 3. Thin section of coal; mainly opaque matter (durain). No. 6 coal, Nashville mine, Washington Co., Ill.

TABLE 2.

PERCENTAGES OF BANDED INGREDIENTS IN COLUMNAR SECTIONS OF COAL BEDS 2, 5, AND 6.

Each Value Represents an Average of Two Determinations.

Coal bed no.	County	Banded coal ingredients				Banded impurities		
		Vitrain	Clarain	Durain	Fusain	Pyrite	Bone	Clay
2	Fulton	17.75	78.52		0.56	2.05		1.12
5	Saline	26.60	69.30		1.80	2.30		
6	St. Clair	13.16	76.51		3.38	5.12		1.83
	St. Clair	7.83	83.09		2.62	4.76		1.70
	St. Clair	9.95	77.58		7.43	1.82	1.33	1.89
	Montgomery	19.5	62.1	14.9	0.8	1.5		1.2
	Washington	13.40	68.70	15.0	2.9			[a]
	Randolph	14.76	75.88		4.77			4.59
	Perry	19.00	69.90		4.50		2.6	4.00
	Franklin	18.81	77.68		1.50	0.42	0.61	0.98
	Franklin	22.70	72.40		2.3	0.10	1.60	0.9
	Williamson	20.10	76.55		1.35		2.0	

[a] Eight-inch clay band removed in mining.

It will be noted that the vitrain content of these coals ranges from 7.83 to 26.6 percent in the bed. Examination of other columns and cores of Illinois coal beds showed that the vitrain content was as much as 24 percent of the bed. Fusain ranges in amount from 0.56 to 7.43 percent and the amount of durain is generally less than 2 percent.[9] Clarain composes very much the largest portion of the coal. No distinction was made between the bright and the gray varieties of clarain.

Analysis of Broken Coal.

General Methods.—The technique of petrographic analysis of broken coal is determined by the fragmentary character and the small size of the material. The most desirable product for microscopic count consists of a small amount of particles which are representative in composition and in which the ingredients are uniformly distributed, permitting the most accurate determinations with the fewest particles counted. Careful sampling is very important.

Two methods of making quantitative determinations of each banded ingredient in broken coal have been used: By measuring their proportional volumes, and by counting particles to obtain proportional numerical percentages. Volumetric measurement of coal ingredients may be made on a polished surface of a disc of plastic material in which coal fragments are mounted. Linear traverses with a microscope having an ocular measuring accessory are made in such manner and in sufficient number to secure volu-

[9] McCabe et al. (Table 2) reported durain in only two samples: Montgomery County 14.9 percent, and Washington County 15.0 percent. These values for durain are very high for Illinois coal and the identification of at least some of the bands of bone coal as durain is possible. However, the No. 6 coal in Washington County is known to contain more than the usual amount of durain or splint coal (Fig. 3) found in Illinois coals.

metric estimates of each ingredient. The linear measurements are accumulated mechanically by an integrating microscope stage. This method has been used frequently in Germany.

The mineral ingredient composition of a crushed ore is commonly determined by counting particles, using an ore-dressing microscope. The same procedure is applicable to the analysis of broken coal. It requires careful sampling, close sizing by sieving, and manual separation and counting of the constituents in the sample. The numerical count of individual particles is converted to percentage estimates of the ingredients by appropriate weighting of the results. The method has been used for a number of years in the examination of broken coal by the Illinois Geological Survey.[10]

Ingredient analysis of the coals by the particle count method was somewhat simplified because in the preparation of the original sample for the stoker tests, all coal less than 8-mesh in size was mainly eliminated, whether this was minus 8-mesh coal in the sample as obtained at the mine or was that produced in crushing the coal in the laboratory. This automatically eliminated a large proportion of the fusain, both that part which originated in layers and lenses and the much smaller quantity occurring as disseminated particles, particularly in the clarain. Fusain offers no serious identification difficulty except when it is extremely fine. Furthermore, the amount of durain or splint coal was very small and not important in any of the coals examined. The problem, therefore, became largely one of differentiating the clarain, particularly the bright clarain, and the vitrain.

The differentiation of clarain and vitrain presented two difficulties: One was the actual recognition of striated clarain in fragments less than 0.1-inch in diameter, and particularly in fragments much less than this size down to about 100-mesh; the other was the differentiation of vitrain and microvitrain.

The recognition of striated structure in fine particles of bright coal depends upon the development of judgment and skill on the part of the operator and the use of somewhat higher magnification than is generally necessary for megascopic identification. The results on the same sample by two trained operators usually checked very closely on the vitrain and clarain content.

Identification of Vitrain and Microvitrain.—Vitrain and microvitrain in clarain have no fundamental differences. Practical solution to the problem of differentiating these substances quantitatively was reached by experimental study of the distribution of banded ingredients in coal crushed to desired sizes.

Attention may be first directed to the determination of vitrain content of the coal and then to the possible errors involved in this determination. On the assumption that the band thickness of vitrain must be 0.1-inch or more, the coal sample was crushed to pass 8-mesh (0.093-inch). This broke up all of the vitrain bands, although undoubtedly not all of it was freed into discrete particles. The preponderant concentration of the crushed coal in relatively large size fragments, commonly more than 70 percent plus 28-mesh (0.02-inch) (Table 3), decreased the probability of microvitrain being freed

[10] McCabe, L. C., Concentration of the banded ingredients of Illinois coals by screening, sizing, and washing: A.I.M.E. Tech. Paper 684, 1936.

TABLE 3.

SCREEN ANALYSES OF HAND-CRUSHED AND OF ROLL-CRUSHED SAMPLES OF VITRAIN, CLARAIN, DURAIN, AND MIXED COAL.

Screens	(1) Vitrain		(2) Vitrain		(3) Vitrain		(4) Clarain		(5) Clarain		(6) Clarain		(7) Durain	
	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %
8×10	49.7	49.7	21.7	21.7	41.6	41.6	25.1	25.1	42.7	42.7	36.3	36.3	36.1	36.1
10×14	19.3	69.0	27.4	49.1	22.2	63.8	20.0	45.1	19.1	61.8	22.0	58.3	24.7	60.8
14×20	11.1	80.1	17.2	66.3	12.6	76.4	14.4	59.5	11.6	73.4	13.0	71.3	14.2	75.0
20×28	6.6	86.7	11.4	77.7	8.0	84.4	9.9	69.4	7.5	80.9	8.9	80.2	8.2	83.2
28×35	4.6	91.3	7.7	85.4	5.2	89.6	8.0	77.4	5.3	86.2	6.0	86.2	5.6	88.8
35×48	3.0	94.3	5.1	90.5	3.8	93.4	6.2	83.6	4.2	90.4	4.6	90.8	4.1	92.9
48×65	2.3	96.6	4.0	94.5	2.8	96.2	5.3	88.9	3.4	93.8	3.5	94.3	2.8	95.7
65×100	1.6	98.2	2.4	96.9	1.8	98.0	4.1	93.0	2.5	96.3	2.5	96.8	1.3	97.5
100×150	0.8	99.0	1.5	98.4	1.0	99.0	2.8	95.8	1.4	97.7	1.3	98.1	1.0	98.5
150×200	0.7	99.7	0.9	99.3	0.8	99.8	1.8	97.6	1.4	99.1	1.2	99.3	0.8	99.3
200×300	0.2	99.9	0.3	99.6	0.18	99.98	0.7	98.3	0.4	99.5	0.4	99.8	0.3	99.6
−300	0.1	100.0	0.4	100.0	0.12	100.0	1.7	100.0	0.5	100.0	0.2	100.0	0.4	100.0

Screens	(8) Mostly clarain		(9) Mixed		(10) Mixed		(11) Mixed		(12) Mixed		(13) Vitrain	
	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %	%	cum. %
8×10	25.4	25.4	22.7	22.7	21.0	21.0	38.4	38.4	—	—	22.5	22.5
10×14	20.0	45.4	24.7	47.4	25.5	46.5	18.5	56.9	—	—	25.5	48.0
14×20	14.5	59.9	15.6	63.0	17.0	63.5	9.3	66.2	—	—	16.5	64.5
20×28	10.4	70.3	10.7	73.7	11.0	74.5	7.0	73.2	—	—	12.0	76.5
28×35	7.4	77.7	7.4	81.1	7.8	82.3	5.3	78.5	34.5	34.5	9.5	86.0
35×48	6.2	83.9	5.7	86.8	5.9	88.2	4.6	83.1	22.3	56.8	5.5	91.5
48×65	4.9	88.8	4.5	91.3	4.4	92.6	3.4	86.5	15.2	72.0	3.8	95.3
65×100	3.8	92.6	3.4	94.7	3.0	95.6	3.0	89.5	10.9	83.9	2.3	97.6
100×150	2.7	95.3	1.9	96.6	1.7	97.3	1.8	91.3	5.9	88.8	1.4	99.0
150×200	1.7	97.0	1.9	98.5	1.5	98.8	2.0	93.3	5.6	94.4	0.6	99.6
200×300	0.7	97.7	0.7	99.1	0.5	99.4	1.1	94.4	1.7	96.1	0.2	99.8
−300	2.3	100.0	0.9	100.0	0.6	100.0	5.6	100.0	3.9	100.0	0.2	100.0

(1) Selected vitrain crushed with roll-crusher to pass 8-mesh.
(2) Selected vitrain crushed with roll-crusher to pass 8-mesh.
(3) Selected vitrain crushed with mortar and pestle to pass 8-mesh.
(4) Selected clarain crushed with roll-crusher to pass 8-mesh.
(5) Selected clarain crushed with roll-crusher to pass 8-mesh.
(6) Selected clarain crushed with mortar and pestle to pass 8-mesh.
(7) Selected durain crushed with roll-crusher to pass 8-mesh.
(8) Selected coal, mostly clarain but with vitrain bands from 1 to 2.5 mm thick, crushed with roll-crusher to pass 8-mesh.
(9) 1½ by ½-inch mixed coal crushed with roll-crusher to pass 8-mesh.
(10) ½-inch by 8-mesh mixed coal crushed with roll-crusher to pass 8-mesh.
(11) Minus 8-mesh mixed coal from 1½-inch mine screenings—breakage from mining and preparation only.
(12) 8 by 10-mesh mixed coal crushed with roll-crusher to pass 28-mesh.
(13) Distribution of vitrain in a crushed sample of mixed coal as determined by petrographic analysis.

from crushed clarain, but undoubtedly some microvitrain bands less than 0.1-inch thick were broken. The counting of vitrain was eventually restricted to material 8 by 28-mesh. All vitrain-like particles (particles strictly fulfilling the criteria requirements) were assigned to vitrain, thus providing the amount of "analytical" vitrain, or the vitrain represented by the analytical value, which may be larger (but is never smaller) than the amount of vitrain actually present. The inclusion of some microvitrain in the count of analytical vitrain introduced a small error which may have been partly compensated by incomplete freeing of plus-0.1-inch vitrain.

TABLE 4.

AMOUNT AND SIZE DISTRIBUTION OF ANALYTICAL VITRAIN OBTAINED BY CRUSHING THREE SELECTED SAMPLES OF CLARAIN WITH WIDE, MEDIUM, AND NARROW BANDS OF MICROVITRAIN RESPECTIVELY.

Screen size	(1)				(2)				(3)			
	Coal retained on screens, grams	Clarain	Vitrain		Coal retained on screens, grams	Clarain	Vitrain		Coal retained on screens, grams	Clarain	Vitrain	
		%	%	Cumulative %		%	%	Cumulative %		%	%	Cumulative %
8×10	12.15	98.0	2.0	11.4	25.4	99.5	0.5	1.9	42.7	100	—	—
10×14	7.37	97.0	3.0	21.8	20.0	97.5	2.5	9.3	19.1	100	—	—
14×20	4.34	95.0	5.0	32.1	14.5	96.0	4.0	17.9	11.6	99.5	0.5	4.5
20×28	2.99	92.0	8.0	43.3	10.4	93.5	6.5	27.9	7.5	99.0	1.0	10.4
28×35	2.01	88.5	11.5	54.2	7.4	89.6	10.4	39.3	5.3	98.0	2.0	18.6
35×48	1.54	85.0	15.0	65.0	6.2	85.0	15.0	53.1	4.2	97.0	3.0	28.5
48×65	1.17	80.0	20.0	76.0	4.9	79.5	20.5	68.0	3.4	95.0	5.0	41.7
65×100	0.82	75.0	25.0	85.7	3.8	73.0	27.0	81.5	2.5	92.0	8.0	57.3
100×150	0.56	73.0	27.0	92.8	2.7	65.0	35.0	91.9	1.4	88.0	12.0	70.4
150×200	0.30	70.0	30.0	97.0	1.7	63.0	37.0	97.9	1.4	84.0	16.0	87.8
200×300	0.13	68.0	32.0	99.0	0.7	64.0	36.0	100.0	0.4	85.0	15.0	92.5
−300	0.07	75.0	25.0	100.0	—	—	—	—	0.6	84.0	16.0	100.0
	Total analytical vitrain in sample of clarain crushed to pass 8-mesh, 6.30%.				Total analytical vitrain in sample of clarain crushed to pass 8-mesh, 6.91%.				Total analytical vitrain in sample of clarain crushed to pass 8-mesh, 1.3%.			
	Analytical vitrain 8×28-mesh, 2.75% of sample.				Analytical vitrain 8×28-mesh, 1.93% of sample.				Analytical vitrain 8×28-mesh, .14% of sample.			

(1) Bright clarain with bands of microvitrain of approximately 1/10-inch maximum width.
(2) Bright clarain with bands of microvitrain of approximately 1/25-inch maximum width.
(3) Bright clarain with bands of microvitrain of approximately 1/50-inch maximum width.

The amount of error resulting from inclusion of microvitrain in the analytical vitrain was investigated (Table 4). Tests with clarain that had microvitrain near the maximum width, 0.1-inch, indicated, for the particular samples used, that less than 2.75 percent of the clarain when crushed, was represented by discrete particles of microvitrain in sizes 8 by 28-mesh. The tests with this clarain, which in crushing probably yielded about the maximum 8 by 28-mesh microvitrain, indicate that for any coal containing much microvitrain near the maximum width, the determined amount of analytical vitrain

will be higher than the actual amount of plus 0.1-inch vitrain. On the other hand, if most of the microvitrain is extremely thin banded, near 0.02-inch, then the contribution of this substance to analytical vitrain is negligible.

Profile measurement of a column of No. 6 coal bed from Franklin County (Table 2) provided a value of 18.8 percent for vitrain more than 0.02-inch wide, of which 25 percent was less than 0.1 inch wide. This would seem to indicate the possibility that the same coal in broken form would contain 33 percent more analytical vitrain, if all microvitrain from 0.1- to 0.02-inch were completely freed and counted, than was present in bands 0.1-inch or more in thickness. However, the greater part of this vitrain from the microvitrain bands is in discrete particles in only the very fine sizes. Hence, if the method of crushing reduces the volume of coal present in such sizes, and if the analysis is based on counts made in the larger sizes (plus 28-mesh) and upon estimates based upon the extrapolation of the values determined from the large sizes, the amount of analytical vitrain derived from the microvitrain is greatly reduced. The experimental evidence supporting this conclusion is presented below.

The original selection of 0.1-inch as the minimum band thickness of vitrain was made mainly in the belief that vitrain bands of lesser thickness would not tend to break away from the adjacent coal to an appreciable extent, at least in natural breakage from mine handling. The tests made, although not conclusive, bear out the assumption.

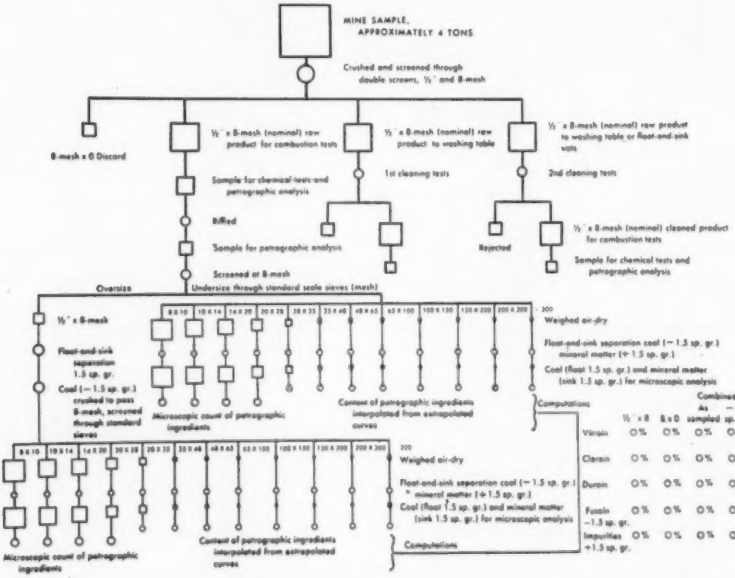
In the sizes below 28-mesh the amount of microvitrain on a weight basis was small, yet was undoubtedly of increasing importance in the vitrain content of each decreasing screen size. Obviously the correct evaluation of the actual vitrain content in these fine sizes cannot depend upon manual separation and count because of the impossibility of differentiating vitrain and microvitrain. Investigation of size-frequency distribution of vitrain, clarain, durain, and microvitrain, when crushed to a desired size and screened in a standard manner, gave information which led to the use of extrapolated curves as probably the best method of estimating the vitrain content of the fine sieve sizes. The development of this procedure is described in the section on petrographic analysis of some prepared stoker coals.

The present studies may give vitrain values a little less than would have resulted from using a lower minimum vitrain thickness, but the objective was accomplished by providing information on the approximate relative amount of vitrain in each of the 14 samples of coal examined. Corresponding data for the different coals used provided the basis for evaluating the possible influence of vitrain on combustion characteristics of the coal. However, in general, there was no evidence of such influence.[11]

Determination of Fusain Content.—Fusain does not behave in crushing with the same degree of conformity as do the other ingredients, and its quantity therefore cannot be determined by the use of the extrapolated curves.

[11] Helfinstine, R. J., and Boley, C. C., Correlation of domestic stoker combustion with laboratory tests and types of fuels. II. Combustion tests and preparation studies of representative Illinois coals: Illinois Geol. Survey Rept. Inv. 120, 1946.

There are generally two varieties, sometimes called hard and soft fusain. Even the hard type is apt to be much softer than vitrain. Also, as fusain is more or less mineralized, a considerable portion of it sinks in organic solutions of 1.5 specific gravity. Therefore fusain was determined by count for each screen size and was considered to represent only the minus 1.5 specific gravity fusain of the original.


MINE SAMPLE, APPROXIMATELY 4 TONS
Crushed and screened through double screens, ½" and 8-mesh
8-mesh x 0 Discard
½" x 8-mesh (nominal) raw product for combustion tests
½" x 8-mesh (nominal) raw product to washing table
½" x 8-mesh (nominal) raw product to washing table or float-and-sink vats
Sample for chemical tests and petrographic analysis
1st cleaning tests
2nd cleaning tests
Riffled
Rejected
Sample for petrographic analysis
½" x 8-mesh (nominal) cleaned product for combustion tests
Screened at 8-mesh
Sample for chemical tests and petrographic analysis
Oversize
Undersize through standard scale sieves (mesh)
½" x 8-mesh
Float-and-sink separation 1.5 sp. gr.
Coal (– 1.5 sp. gr.) crushed to pass 8-mesh, screened through standard sieves
8 x 10
10 x 14
14 x 20
20 x 28
28 x 35
35 x 48
48 x 65
65 x 100
100 x 150
150 x 200
200 x 300
200
Weighed air-dry
Float-and-sink separation coal (– 1.5 sp. gr.) mineral matter (+ 1.5 sp. gr.)
Coal (float 1.5 sp. gr.) and mineral matter (sink 1.5 sp. gr.) for microscopic analysis
Microscopic count of petrographic ingredients
Content of petrographic ingredients interpolated from extrapolated curves
Computations
Combined As – 1.5 sampled sp. gr.
½" x 8
8 x 0
Vitrain 0% 0% 0% 0%
Clarain 0% 0% 0% 0%
Durain 0% 0% 0% 0%
Fusain – 1.5 sp. gr. 0% 0% 0% 0%
Impurities + 1.5 sp. gr. 0% 0% 0% 0%

FLOW DIAGRAM
PETROGRAPHIC ANALYSIS OF STOKER COALS

FIG. 4.

Determination of Mineral Matter Content.—Mineral matter was separated from the coal in a heavy liquid of 1.5 specific gravity (Fig. 4). A preliminary separation removed substance of considerable hardness, such as pyrite, before the first crushing. A second float-and-sink separation was made, after breaking the coal to desired sizes, in order to remove additional mineral matter. The content of the first sink was derived from partings and lenses of rock and mineral matter associated with the bed coal and included shale, bone coal, and pyrite. The refuse from the second float-and-sink separation was derived from fracture surfaces, veinlets, fine bands and lenses, and disseminated particles, all associated with lump coal; it included bone

coal, calcite, pyrite, clay, kaolinite, and mineralized fusain. A more complete analysis of mineral content is possible than was practiced in this work.[12]

Particles of coal firmly attached to a mineral fragment are sometimes found in the sink material. More rarely a fragment of coal is found which, because of its weight, is assumed to contain an unusual concentration of disseminated minerals, probably pyrite, sufficient to raise the specific gravity above 1.5. The relative quantity of such coal in the sink examined in these analyses was very small and was considered of no importance. The quantity of fusain found in the sink is often a considerable proportion of this substance, depending upon the extent and character of mineralization. Perhaps a third or more of the fusain in coal is commonly heavier than 1.5 specific gravity. It has been mentioned that most of the fusain in the coals tested was removed in the laboratory preparation of mine samples.

PROCEDURE OF PETROGRAPHIC ANALYSIS.

The three essential steps in the quantitative petrographic analysis of broken coal using ore-dressing technique are sampling, sizing, and separating and counting the discrete particles of each of the ingredients in the coal.

One objective was the exploration of possible differences in stoker performance resulting from variations in coal type. Such variations would be the result of differences in the relative content of the banded ingredients, particularly vitrain, clarain, and durain. As the initial material used in the combustion tests was broken coal of small size (minus ½-inch) and its character was variously modified by preparation processes, the only known means of determining its ingredient composition or type was by some petrographic procedure.

Lot Sampling and Crushing.—The initial lots of coal were obtained from material usually designated as 1¼-inch unwashed screenings, but two lots of mine-run coal and one lot of specially prepared 7/16-inch by 10-mesh stoker coal were also obtained.

Starting with the original lot of 3 to 5 tons of coal, which was obtained without special sampling procedure, a product defined as ½-inch by 8-mesh nominal raw stoker coal (Fig. 4) was prepared by crushing and screening in the laboratory for the combustion tests. (As a rule, less than 10 percent of minus 8-mesh fines was included in the coal as burned.) During this sizing preparation, increment samples were taken until about 150 pounds were accumulated. About 40 pounds were cut out as the primary petrographic analysis sample. By passing this 40-pound sample through Jones-type riffles, about 5½ pounds were secured for the petrographic assay.

The 5½-pound sample was screened through an 8-mesh sieve to separate the undersize coal, which was set aside for separate microscopic analysis, thus providing the first lot of undersize minus 8-mesh coal. The ½-inch by 8-mesh oversize was immersed in CCl_4 solution of 1.5 specific gravity

[12] Ball, Clayton G., Mineral matter of No. 6 bed coal at West Frankfort, Franklin County, Illinois—Contributions to the study of coal: Illinois Geol. Survey Rept. Inv. 33, 1935. Sprunk, George C., and O'Donnell, H. J., Mineral matter in coal: U. S. Bur. Mines Tech. Paper 648, 1942.

to remove by float-and-sink separation the non-coal substances, mostly mineral matter, thus arbitrarily defined on the basis of specific gravity. The minus 1.5 specific gravity coal of ½-inch by 8-mesh dimensions was crushed with a spring-type double-roll crusher equipped with attachments to reduce to a minimum the loss of material during breakage. Four passes to crush all the coal as desired were usually necessary with the rolls set at 0.093-inch, 0.075-inch, 0.050-inch, and 0.025-inch apart. Successive passes through reduced openings of the rolls were necessary to break the extremely flat pieces which pass the rolls but are retained on the square-hole sieve. The crushed product of each pass was screened on the 8-mesh sieve which has an opening 0.093-inch square. This gave a second lot of minus 8-mesh coal for microscopic analysis.

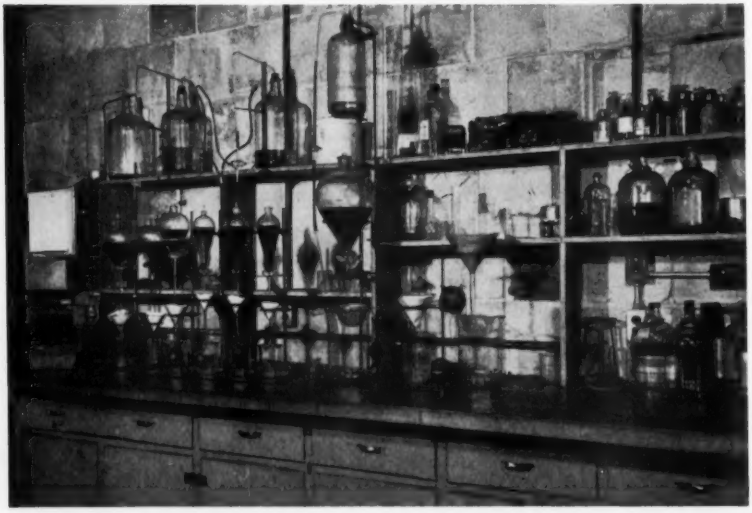


FIG. 5. Laboratory equipment for preparing samples for petrographic analysis.

Use of Roll-Type Crusher.—The roll-type crusher was used because tests demonstrated that the size-frequency distribution of the broken coal fed evenly through the roll crusher was essentially the same as resulted when coal was hand-crushed carefully with mortar and pestle (Table 3).

In making these tests, small batches of a few grams each of coal were put into a large size mortar. The large pestle was dropped of its own weight from the height of six inches for 15 consecutive times, being careful to avoid a grinding motion. The broken coal was then poured over an 8-mesh screen and the oversize returned to the mortar for further breakage. By crushing all the coal to pass 8-mesh it was believed that most bands of vitrain thicker

than the minimum thickness would be resolved into discrete particles generally unattached to other coal. A few hundred grams of coal were crushed in each test and a screen analysis made.

The two lots of 8-mesh by 0 coal had undergone different stages of breakage in being reduced in size composition, and they were therefore given independent microscopic analysis. Both lots were screen-sized, using the series from 8-mesh to 300-mesh, and the screen weights were recorded.

Gravity Classification of Screen Fractions.—Each sieve fraction was immersed in CCl_4 solution of 1.5 specific gravity to remove all mineral substance freed in the crushing operations (Fig. 5). Immersion also cleaned the individual grains and facilitated identification. Two sets each of minus 1.5 specific gravity coal and plus 1.5 specific gravity mineral matter, sized and weighted, were obtained.

FIG. 6. Laboratory equipment used in petrographic analysis.

Separation and Counting.—The contents of each screen size were first mixed thoroughly by gentle tumbling from a full (Fig. 5) to an empty beaker. With a small flexible blade spatula, about 100 particles were obtained and distributed evenly over a cleaned and polished Petrie dish which was placed upon the microscope stage on a Greenough type ore-dressing binocular (Fig. 6). A black velvet cloth spread beneath the microscope absorbed the light transmitted through the Petrie dish.

Small dissecting needles with modified points and fine pointed tweezers were used to manipulate particles of coal and to move them out of the way when identified and counted. A Wetzlar type microscope light with a 100-watt lamp was used. This light is so made that the amount of illumination in the microscope field can be varied by adjusting the focus. Three sets of ocular lenses, 8X, 12.5X, 18X, and five objective lenses, .75X, 1X, 2X, 3X, and 6X, were used in the binocular to get the desired magnifications.

After all the particles in the first increment had been identified and counted, the procedure continued until 1,500 particles were classified and counted. This number, in a well mixed sample, proved sufficient to give percentage figures that could be duplicated within one percentage point by successive counts. Occasionally as few as 1,000 or 750 particles were counted and at the other extreme as many as 2,000 or 2,500, but a standard count of 1,500 particles was the rule (Fig. 7).

A Clay-Adams multiple laboratory counter was used in counting the particles. This is a finger manipulated, integrated counting device having five recording units and a totalizer. When 100 particles are counted a bell signal is sounded by the instrument, and at this point in the count the observer can read directly the percentage of each ingredient. This feature is a distinct advantage, for, by recording the percentages of each increment count, a continuous picture of percentage distribution is built up as the counting progresses, and the observer can tell whether or not the sample is well mixed, and how many increments it will probably be necessary to count in order to get satisfactory results.

Origin and Character of Sample Analyzed.—The coal used in the petrographic analysis consisted of samples of the ½-inch by 8-mesh material as prepared for the combustion tests. The elimination of the minus 8-mesh coal from the original sample and from the crushed oversize was not perfect, and hence the final sample may be spoken of as ½-inch by 8-mesh nominal. The sample of this coal obtained for petrographic analysis was crushed to pass an 8-mesh screen. It is apparent that this 8-mesh material came from three sources: the coal which actually was between ½-inch and 8-mesh in size, undersize coal not screened out of the original sample, and undersize coal produced from crushing of the oversize. In general it is evident that the greater part of the minus 8-mesh material used in the petrographic analysis was produced by crushing and a very small part by natural breakage.

Bases of Analytical Data.—The percentage figures for the different banded ingredients were obtained on a basis of minus 1.5 specific gravity material, since all material before analysis was subjected to float-and-sink separation in a liquid of 1.5 specific gravity. Calculation to an "as received" or "as sampled" basis was readily possible by allowing for the percentage of non-coal material rejected at 1.5 specific gravity. Percentages in the "as sampled" or "as received" form give the relative quantity of the petrographic ingredients in the stoker coals as prepared for the combustion tests.

Composition of Extremely Fine Sizes.—Most of the labor and a large part of the strain of counting the coal particles was concentrated in the very

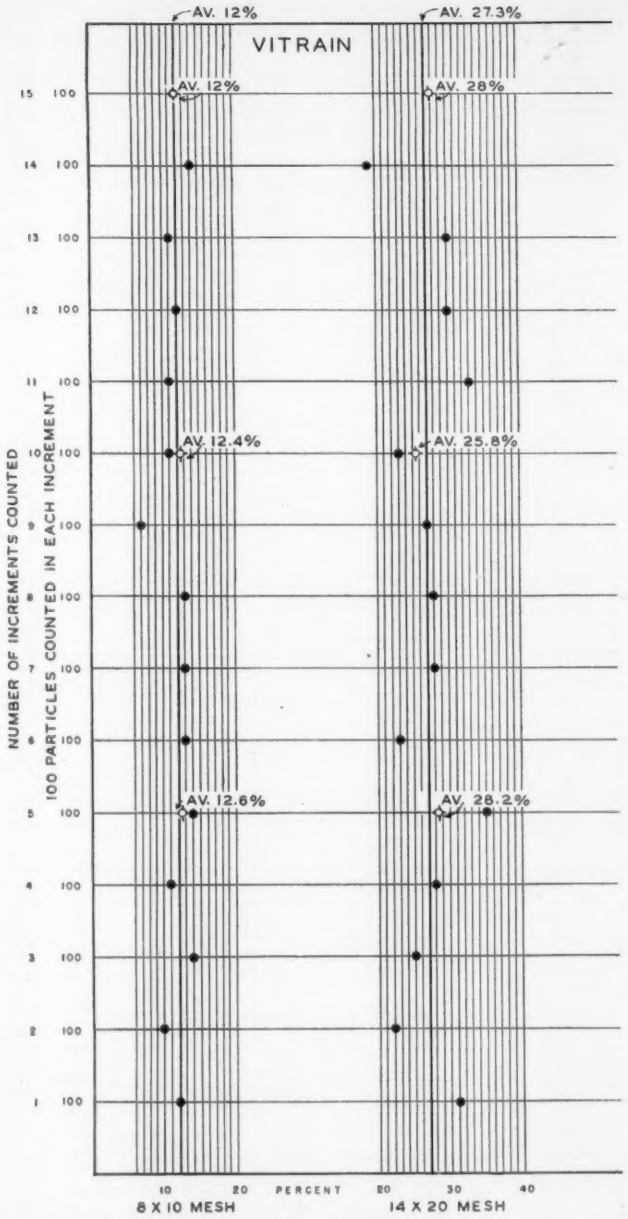


FIG. 7a. Comparison of vitrain and clarain determinations in four screen-size fractions in lots of 100 particles and of average of 500 and 1,500 particle lots.

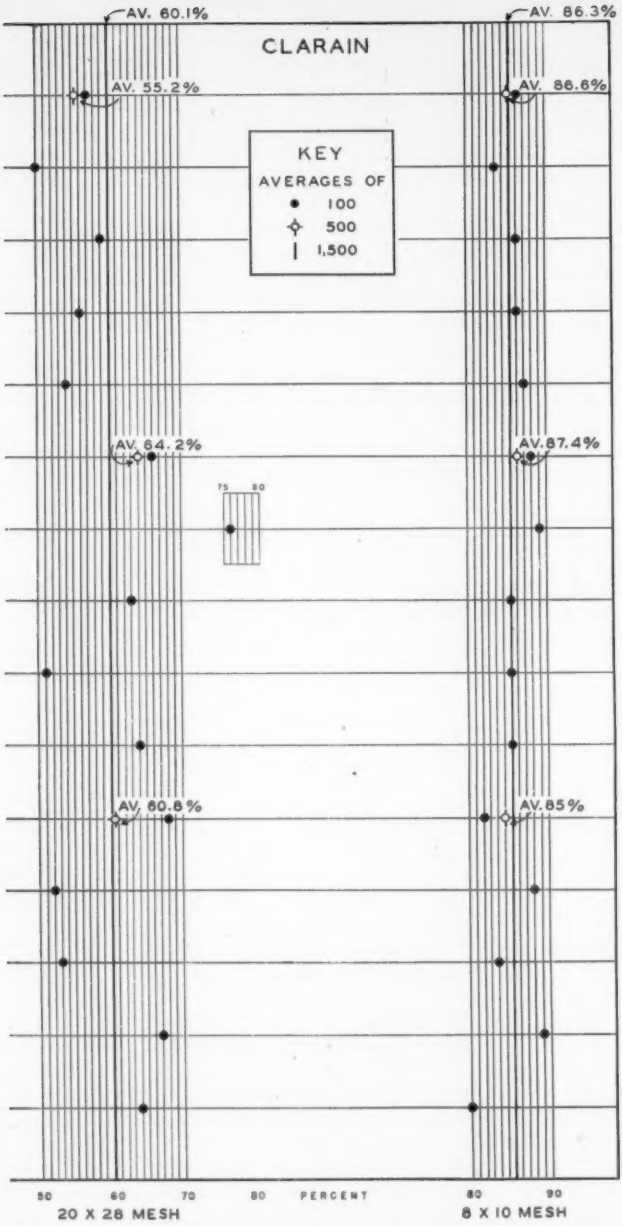


FIG. 7b (continued). Comparison of vitrain and clarain determinations in four screen-size fractions in lots of 100 particles and of average of 500 and 1,500 particle lots.

fine screen sizes below 28-mesh. It was desirable to obviate as much of this labor and strain as possible, and thereby reduce the time required for the analysis. The details of the procedure whereby the final method was developed and its validity tested are given in the section on Ingredient Distribution, but the method is briefly described here.

TABLE 5.

VITRAIN CONTENT OF A COLUMNAR SECTION OF NO. 6 COAL, FRANKLIN COUNTY, BY PROFILE ANALYSIS, AND OF BROKEN RAW AND SPECIAL STOKER COAL FROM THE SAME MINE BY SCREEN SIZES INCLUDING TABULATIONS OF THE SIZE-FREQUENCY DISTRIBUTION FOR THE BROKEN COAL.

	% Vitrain		% Vitrain
A. Columnar section, vitrain + 0.5 mm.	18.8		
B. Columnar section, vitrain + 1/10-inch	14.1		
C. 1½-inch raw screenings, vitrain + 1/10-inch	16.1		
C_1. 1½″ × ¼″ (52% of C), vitrain + 1/10-inch	12.3	Floated 24% of C_1	15.7
C_2. ¼″ × 8 mesh (35% of C), vitrain + 1/10-inch	18.0	Floated 24% of C_2	28.7
C_3. 8m × 0 (13% of C), vitrain + 1/10-inch	25.9	Floated 12% of C_3	57.9
C_4. 8m × 48, vitrain + 1/10-inch	29.5	Floated 53% of C_4	39.2
D. 7/16″ × 10 M mine prepared Stoker coal, vitrain + 1/10-inch	26.5		

D_1 Size-frequency distribution of vitrain in D (above)			C_3 Size-frequency distribution of vitrain in −¼″ sizes of C (above)		
Size mesh	% of sample (D)	Vitrain content %	Size mesh	% of sample (C)	Vitrain content %
7/16″×3	25.3	20.0	½″×3	15.1	18.0
3×4	24.7	24.0	3×4	7.1	20.0
4×6	22.0	27.0	4×6	5.6	22.0
6×8	14.3	30.0	6×8	4.1	25.0
8×10	6.9	32.0	8×10	3.3	27.0
10×14	3.0	37.0	10×14	2.4	28.0
14×20	1.7	42.0	14×20	1.2	31.0
20×28	0.8	43.0	20×28	0.9	34.0
28×35	0.4	43.0	28×35	0.7	30.0
35×48	0.3	43.0	35×48	0.6	23.0
48×65	0.2	38.0	48×65	0.45	22.0
65×100	0.1	25.0	65×100	0.40	16.0
100×150	−0.1	22.0	100×150	0.23	17.0
150×200	−0.1	10.0	150×200	0.24	8.0
200×300	−0.1	10.0	200×300	0.13	5.0

Investigation showed that the size-frequency distribution of hand-picked vitrain, clarain, and durain, when crushed under identical conditions, conformed essentially in terms of weight percentages retained on standard scale sieves. This discovery provided the basis for the assumption that when a *mixture* of the banded ingredients was crushed, the size-frequency distribution of the different ingredients would be essentially uniform, provided that undersized particles were readily freed from the crusher and that the grinding action of particle against particle was reduced to a minimum.

Accordingly, in order to determine the vitrain content of a suitably screen-sized sample, it was found necessary to determine the amount of vitrain present in only a few of the screen fractions and, on the basis of a curve of the same class as that representing the size distribution data for the sample as a whole, to estimate the percentage of the ingredients present in the fine screen sizes. A graph form was used, having for its horizontal scale the ratio of the standard scale sieves (Fig. 8). It is believed that greater ac-

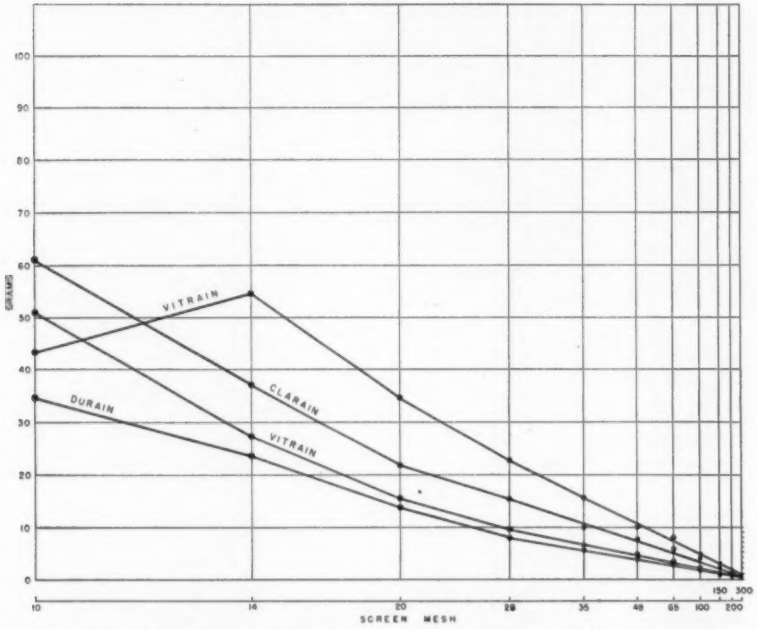


FIG. 8a. Method of extrapolating curves for fine sizes and of interpolating values for banded ingredients. True plot of weight distribution of screen fractions of selected samples of banded ingredients roll-crushed to pass 8-mesh.

curacy in estimating percentages is obtained by this method than by laborious and difficult counting of the fine particles, because of the errors introduced through the appearance in the very fine sizes of increasing percentages of microvitrain derived from the clarain. The nature and extent of this error are discussed in detail in the section on Ingredient Distribution.

PETROGRAPHIC ANALYSIS OF PREPARED STOKER COALS.

This section presents the results of the petrographic analysis of the coals used in the stoker tests as specially prepared in the laboratory by routine tabling or by float-and-sink methods.

Source of Samples.—The large lot samples procured for the preparation and combustion of domestic stoker coals came from 15 mines located in representative mining areas and included the most commonly worked coal beds in the State (Fig. 9). Fourteen of the samples represented coals of low rank bituminous B and C. One sample came from a mine in Eagle Valley that produces high volatile bituminous A coal from Harrisburg (No.

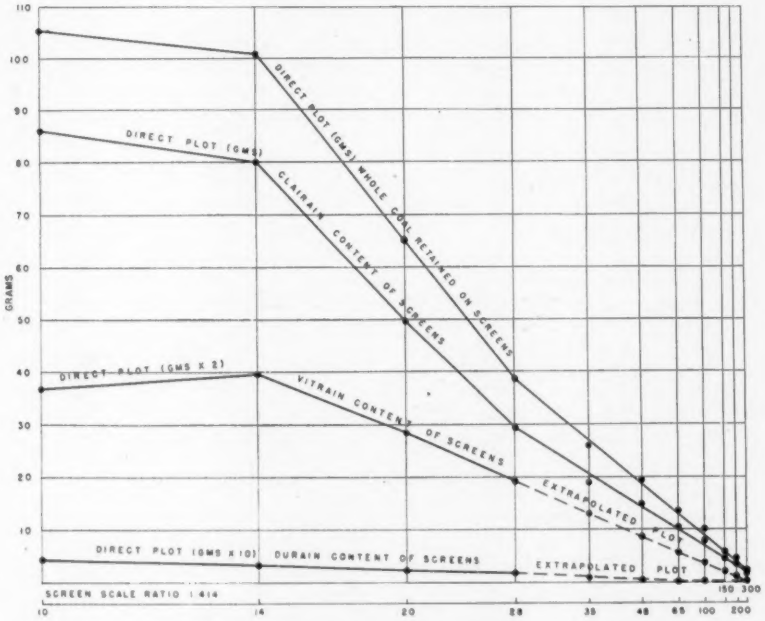


FIG. 8b (continued). Method of extrapolating curves for fine sizes and of interpolating values for banded ingredients. Plot of weight distribution of screen fractions of whole coal and of individual banded ingredients determined petrographically. Vitrain and durain determined by extrapolation below 28-mesh.

5) coal bed. Coal of this relatively high rank is found in no other mining district in the State. One of the samples was obtained from the Friendsville coal bed near Mt. Carmel, a coal bed lying near the surface in parts of Wabash County and occurring several hundred feet above the main coal-bearing level.

Pertinent information relating to the source of the samples is given in Table 6, and the state-wide distribution of the mine samples is shown on the accompanying map, Figure 9.

Laboratory Routine of Coal Preparation.—The 3- to 6-ton coal samples brought from the mine to the laboratory were first passed over vibrating double screens of ½-inch and 8-mesh openings, with the oversize being reduced by crushing to pass the top screen. The undersized material was discarded. The screened coal was divided into three parts, one to be used directly for combustion tests and the others to be subjected to coal cleaning processes before combustion (Fig. 4).

TABLE 6.

SOURCE AND DESCRIPTION OF SAMPLES.

Lab. No.	County	Coal bed	Mining district[a]	County rank index[b]	Rank, high volatile A, B, or C	Description of coal
1	Franklin	Herrin No. 6	Franklin-Williamson	131	B	Washed stoker, 7/16" by 10-mesh
2	LaSalle	LaSalle No. 2	LaSalle	122	C	Raw 1¼" stoker
3	Vermilion	Grape Creek	Danville	122	C	1¼" screenings, dedusted
5	Macoupin	Herrin No. 6	Central Illinois	121	C	1¼" screenings
6	Peoria	Springfield No. 5	Fulton-Peoria	122	C	1¼" screenings
7	Gallatin	Harrisburg No. 5	Eagle Valley	145	A	Mine run
8	Wabash	Friendsville	Mt. Carmel	122	C	Largely 2" or 3" screenings with some lump
9	St. Clair	Herrin No. 6	Belleville	126	C	Mine run. Considerable fine coal included
10	Saline	Harrisburg No. 5	Saline	137	B	Stoker. 1½" by 10-mesh
11	Vermilion	Danville No. 7	Danville	125	C	Small stoker, 1" by 8-mesh
12	Sangamon	Springfield No. 5	Springfield	121	C	Largely stoker, 1" by 5/16", with some 5/16" by 0
13	Randolph	Herrin No. 6	Southwestern Illinois	126	C	Crushed 1½" by ¾"
14	Christian	Herrin No. 6	Central Illinois	123	C	1½" screenings
15	Williamson	Herrin No. 6	Franklin-Williamson	133	B	1½" dedusted screenings
16	Knox	Rock Island No. 1	Northwestern Illinois	123	C	Stoker, 1" by ¼"

[a] Designation of mining districts approximately as used in: Bement, A., Illinois coal: Illinois Geol. Survey Bull. 56, p. 23, 1929.

[b] Average heating value expressed in hundreds of B.t.u. per pound on a moist mineral-matter-free basis, for face samples reported up to October, 1934. See: Cady, Gilbert H., Classification and selection of Illinois coals: Illinois Geol. Survey Bull. 62, 354 pp., 1935.

Effect of Routine Preparation on Vitrain Distribution.—The petrographic analyses are of special interest in connection with the combustion tests because they reveal the extent to which the coal cleaning processes affected the petrographic composition of the coal. The nature of these effects can be determined by consideration of the accompanying data (Tables 7 and 8). An

increase in vitrain content is the usual but not the invariable rule. The initial average vitrain content of the raw stoker coals (excluding 1A) was 9.2 percent (10.6 percent on a minus 1.5 specific gravity basis). The average vitrain content after the first cleaning was 10.5 percent (11.1 percent, minus 1.5 specific gravity), an increase of 14 percent; and after the second

DISTRIBUTION OF MINES SAMPLES

FIG. 9. Location of mines from which samples were obtained.

cleaning 11.8 percent (12.2 percent, minus 1.5 specific gravity), an increase of 28 percent over the initial amount. On the minus 1.5 specific gravity basis the vitrain content ranged from 1.5 percent (8 A) to only 14.5 percent (15 A) in the untreated coal and was no higher than 19.2 percent in the improved coals (15 B).

TABLE 7.

ANALYSES OF 40 STOKER COALS IN TERMS OF BANDED INGREDIENTS ON AN "AS FIRED" AND A MINUS 1.5 SPECIFIC GRAVITY BASIS.

Lab. No.[a]	Lab. treatment	Banded ingredients "as fired" basis						Banded ingredients −1.5 sp. gr. basis			
		Vitrain %	Clarain %	Durain %	Fusain %	+1.5 sp. gr. impur. %	Ash ch. an. %	Vitrain %	Clarain %	Durain %	Fusain %
1A	None	26.5	66.8	1.2	1.3	4.2	7.2	27.7	69.7	1.3	1.3
3A	Crushed and screened	12.8	66.9	2.0	1.1	17.2	15.0	15.5	80.8	2.4	1.3
3B	Washing table	16.3	75.2	1.9	1.2	5.4	8.0	17.2	79.5	2.0	1.3
3C	Washing table	14.2	81.1	1.3	1.0	2.4	6.7	14.6	83.1	1.3	1.0
5A	Crushed and screened	9.8	80.5	1.7	1.4	6.6	16.6	10.4	86.2	1.9	1.5
5B	Washing table	12.3	81.2	1.9	0.9	3.6	9.3	12.7	84.3	2.0	1.0
5B[1]	Washing table	13.2	79.6	1.5	0.7	5.0	8 8	13.9	83.7	1.6	0.8
6A	Crushed and screened	10.8	71.2	1.6	0.7	15.7	15.5	12.8	84.4	1.9	0.9
6B	Washing table	12.4	82.5	0.9	0.4	3.8	9.2	12.9	85.7	1.0	0.4
6B[1]	Washing table	13.4	80.7	0.9	0.6	4.4	9.6	14.0	84.4	1.0	0.6
7A	Crushed and screened	5.7	79.7	0.5	0.5	13.6	13.9	6.6	92.2	0.6	0.6
7B	Washing table	5.2	87.2	0.9	0.5	6.2	10.4	5.5	93.0	0.9	0.6
7C	Washing table	5.1	89.0	0.3	0.6	5.0	9.8	5.4	93.7	0.4	0.6
8A	Crushed and screened	1.5	75.3	1.7	0.2	21.3	20.8	1.9	95.7	2.2	0.2
8B	Washing table	1.7	84.7	1.0	0.1	12.5	13.5	1.9	96.8	1.2	0.1
8C	Washing table	1.9	87.3	2.7	0.1	8.0	11.7	2.0	95.0	2.9	0.1
9A	Crushed and screened	7.2	69.5	1.1	0.5	21.7	19.3	9.2	88.8	1.3	0.7
9B	Washing table	6.8	82.2	0.7	0.4	9.9	12.0	7.6	91.2	0.7	0.5
9C	Float-and-sink	12.3	86.5	0.4	0.3	0.3	4.9	12.4	86.9	0.4	0.3

[a] Lab. Nos. are the same as those used in Illinois Geol. Survey Rept. Inv. 120.

TABLE 7—*Continued.*

Lab. No.	Lab. treatment	Banded ingredients "as fired" basis						Banded ingredients −1.5 sp. gr. basis			
		Vitrain %	Clarain %	Durain %	Fusain %	+1.5 sp. gr. impur. %	Ash ch. an. %	Vitrain %	Clarain %	Durain %	Fusain %
10A	Crushed and screened	14.5	74.1	3.0	1.7	6.7	9.8	15.5	79.8	3.2	1.5
10B	Washing table	17.7	76.7	1.2	0.9	3.5	7.2	18.3	79.5	1.2	1.0
10C	Washing table	17.9	78.9	1.3	0.9	1.0	6.0	18.1	79.6	1.4	0.9
11A	Crushed and screened	7.4	70.0	0.7	0.7	21.2	17.4	9.3	88.9	0.9	0.9
11B	Washing table	10.7	80.1	1.1	0.7	7.4	10.5	11.6	86.5	1.1	0.8
11C	Washing table	9.3	86.1	0.5	0.7	3.4	8.4	9.7	89.1	0.5	0.7
12A	Crushed and screened	7.9	76.7	1.0	0.7	13.7	13.9	9.1	88.9	1.2	0.8
12B	Washing table	8.2	83.0	0.9	0.7	7.2	9.9	8.9	89.4	1.0	0.7
12A[1]	Washing table	9.6	79.5	0.8	0.7	9.4	12.4	10.5	87.8	0.9	0.8
13A	Crushed and screened	8.6	72.3	1.1	0.6	17.4	15.9	10.4	87.5	1.3	0.8
13B	Washing table	8.6	80.1	1.6	0.4	9.3	11.5	9.5	88.2	1.8	0.5
13C	Washing table	11.4	81.9	1.4	0.7	4.6	9.2	11.9	85.9	1.5	0.7
14A	Crushed and screened	11.2	71.0	1.5	1.0	15.3	12.1	13.2	83.8	1.8	1.2
14B	Washing table	11.5	82.0	1.2	1.1	4.2	8.2	12.0	85.6	1.3	1 2
14C	Washing table	14.1	80.8	1.4	1.0	2.7	7.3	14.5	83.0	1.5	1.0
15A	Crushed and screened	14.5	78.4	1.2	0.5	5.4	7.9	15.3	82.8	1.3	0.6
15B	Washing table	18.1	78.3	0.7	0.7	2.2	6.9	18.5	80.0	0.8	0.7
15C	Float-and-sink	19.2	80.3	—	0.3	0.2	2.8	19.2	80.5	—	0.3
16A	Crushed and screened	7.4	76.9	2.0	0.9	12.8	11.5	8.5	88.2	2.3	1.0
16B	Washing table	9.5	84.4	1.4	0.8	3.9	8.1	9.8	87.9	1.5	0.8
16C	Float-and-sink	9.4	87.5	1.6	0.8	0.7	4.6	9.5	88.1	1.6	0.8

Comparison with Previous Analyses of Column Sample.—For 10 column samples of coal obtained from southern Illinois (Table 2) McCabe [13] reported an average vitrain content, on the basis of a minimum thickness of 0.5 mm. for vitrain, of 16.9 percent. The average vitrain content of six raw stoker coals of the present set prepared from mine screenings samples also collected from southern Illinois mines, was 13.4 percent. The fact that these mine samples did not include the minus 8-mesh material reduced somewhat the quantity of vitrain reported, and the further fact that vitrain bands between 0.1- and 0.2-inch were included in the column sample measurements gave a somewhat larger value for these than would have been obtained had the critical width been 0.1-inch. Even so, the comparisons indicate that the content of vitrain in raw untreated screenings is probably not greatly different from that of the coal in the bed.

TABLE 8.

VITRAIN CONTENT OF 13 RAW AND CLEANED STOKER COALS ARRANGED IN ORDER OF INCREASING VITRAIN CONTENT, ON THE "AS FIRED" BASIS.

Lab. No.	½" × 8-mesh raw stoker coal Vitrain content		Lab. No.	1st cleaning, stoker coal product Vitrain content		Lab. No.	2nd cleaning, stoker coal product Vitrain content	
	As fired %	−1.5 sp. gr. %		As fired %	−1.5 sp. gr. %		As fired %	−1.5 sp. gr. %
8A	1.5	1.9	8B	1.7	1.9	8C	1.9	2.0
7A	5.7	6.6	7B	5.2	5.5	7C	5.4	5.4
9A	7.0	9.2	9B	6.8	7.6	9C	12.3	12.4
16A	7.4	8.5	16B	9.5	9.8	16C	9.4	9.5
11A	7.4	9.3	11B	10.7	11.6	11C	9.3	9.7
12A	7.9	9.1	12B	8.2	8.9	12A[1]	9.6	10.5
13A	8.6	10.4	13B	8.6	9.5	13C	11.4	11.9
5A	9.8	10.4	5B	12.3	12.7	5B[1]	13.2	13.9
6A	10.8	12.8	6B	12.4	12.9	6B[1]	13.4	14.0
14A	12.2	13.2	14B	11.5	12.0	14C	14.1	14.5
3A	12.8	15.5	3B	14.2	14.6	3C	16.3	17.2
10A	14.5	15.5	10B	17.7	18.3	10C	17.9	18.1
15A	14.5	15.3	15B	18.1	18.5	15C	19.2	19.2
Av.	9.2	10.6	Av.	10.5	11.1	Av.	11.8	12.2

Comparison of Tabling and Float-and-Sink Preparation.—The influence of preparation processes upon the ingredient contents is shown by the results obtained by preparing two coals by both concentrating table and float-and-sink methods (Table 9). In the case of coal No. 15, for which the vitrain concentration was the larger, even with a recovery of coal by the float-and-sink method of less than 50 percent, the amount of vitrain in the recovered coal was only 18.5 percent in one trial and 19.2 percent in the other. Coal No. 15 (Williamson County) is of particular interest because its vitrain content, although prepared under conditions favorable to high vitrain con-

[13] McCabe, L. C., Concentration of banded ingredients of Illinois coals by screen-sizing and washing: A.I.M.E. Tech. Paper 684, p. 6, 1936.

centration, was actually less than the vitrain content of mine-prepared stoker coal from Franklin County (Table 7, 1A). The inference would seem to be warranted that for the coal used, even under exacting conditions of recovery such as float-and-sink, very little more concentration of vitrain is accomplished than is effected by table washing with rejects in the order of only 15 percent.

TABLE 9.

COMPARISON OF VITRAIN CONTENT OF COALS CLEANED BY TABLE WASHING AND FLOAT-AND-SINK SEPARATION.

As sampled basis (Coal plus impurities)				−1.5 sp. gr. coal basis (Coal less separable impurities)			
Coal	Vitrain %	Coal	Vitrain %	Coal	Vitrain %	Coal	Vitrain %
16A Raw	7.4	16A Raw	7.4	16A Raw	8.5	16A Raw	8.5
16B Washed	9.5	16C F. & S.	9.4	16B Washed	9.8	16C F. & S.	9.5
	+2.1		+2.0		+1.3		+1.0
15A Raw	14.5	15A Raw	14.5	15A Raw	15.3	15A Raw	15.3
15B Washed	18.1	15C F. & S.	19.2	15B Washed	18.5	15C F. & S.	19.2
	+3.6		+4.7		+3.2		+3.9

16A = Raw stoker coal.
16B = Stoker coal cleaned on washing table, 14.3% of 16A rejected.
16C = Stoker coal cleaned by float-and-sink, 56% of 16A rejected.
15A = Raw stoker coal.
15B = Stoker coal cleaned on washing table, 18.2% of 15A rejected.
15C = Stoker coal cleaned by float-and-sink, 53.5% of 15A rejected.

Comparison of Analyses of Column Sample and Two Varieties of Mine Samples of Fine Coal from Same Mine.—On the possibility that the composition of raw screenings (1½-inch by 0) might be somewhat different from that of the mine prepared stoker coal (7/16-inch by 10-mesh) used in the stoker tests, a study of the petrographic composition of each was made. There are assembled in the accompanying table (Table 5) vitrain percentages for the bed column (Table 2), for the mine prepared stoker coal (Table 7, 1A), for the raw 1½-inch screenings specially determined, for the four sized fractions of these screenings, and also for the float products (1.5 specific gravity) of each of the four sized products, all representing coal from the same Franklin County mine. In addition the table gives the size-frequency distribution values for vitrain for the 7/16-inch by 10-mesh mine-prepared stoker coal and the ½-inch raw screenings.

In the columnar sample the vitrain content was approximately 18.8 percent of the bed coal in this mine (Table 2). The vitrain content of other columnar sections from the same coal bed in the same general mining region is shown by Survey records to approximate the figure given here. The records also

indicate that of the vitrain measured in this columnar section, 75 percent was in bands thicker than 0.1-inch and 25 percent in bands between 0.1-inch and 0.02-inch wide.

The raw 1½-inch screenings is a broken coal product estimated to represent about ⅓ of the mined coal bed. In it the vitrain content (plus 0.1-inch) by petrographic analysis was found to be 16.1 percent, an increase over that of the bed coal of only 2 percentage points or about one-seventh. Although this increase of 14 percent is an appreciable amount percentage-wise, it does not represent any notable concentration.

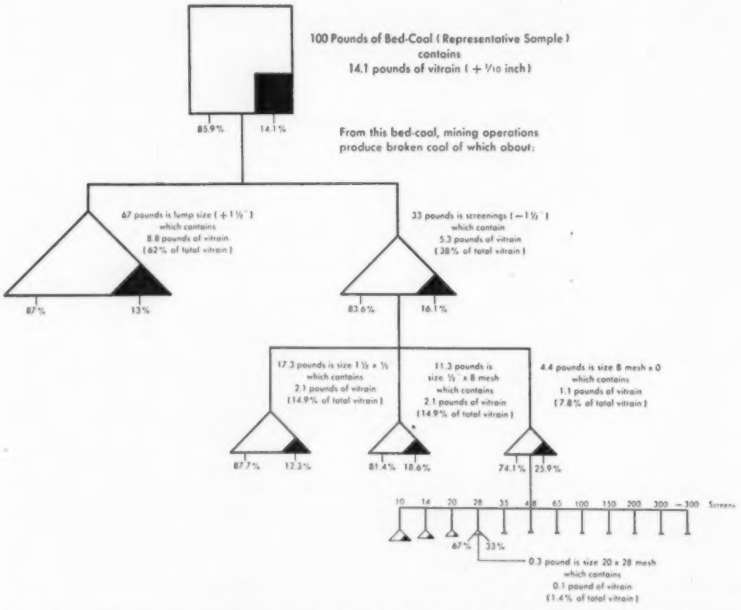

100 Pounds of Bed-Coal (Representative Sample) contains 14.1 pounds of vitrain (+ 1/10 inch)
85.9%
14.1%
From this bed-coal, mining operations produce broken coal of which about:
67 pounds is lump size (+ 1½") which contains 8.8 pounds of vitrain (62% of total vitrain)
87%
13%
33 pounds is screenings (− 1½") which contain 5.3 pounds of vitrain (38% of total vitrain)
83.6%
16.1%
17.3 pounds is size 1½ x ½ which contains 2.1 pounds of vitrain (14.9% of total vitrain)
87.7%
12.3%
11.3 pounds is size ½" x 8 mesh which contains 2.1 pounds of vitrain (14.9% of total vitrain)
81.4%
18.6%
4.4 pounds is size 8 mesh x 0 which contains 1.1 pounds of vitrain (7.8% of total vitrain)
74.1%
25.9%
10
14
20
28
35
48
65
100
150
200
300
− 300
Screens
67%
33%
0.3 pound is size 20 x 28 mesh which contains 0.1 pound of vitrain (1.4% of total vitrain)

FIG. 10. Diagrammatic representation of vitrain distribution of various sizes of naturally broken coal based on petrographic analysis.

The distribution of this variation in vitrain content in terms of the size fractions was as follows: The 1½-inch by ½-inch product, consisting of 52 percent of the screenings, contained 12.3 percent vitrain, which is about 13 percent less than the bed coal. The ½-inch by 8-mesh fraction contained 18 percent vitrain, indicating a tendency toward concentration as size decreases, a tendency which results in an increase to 25.9 percent vitrain in the 8-mesh by 0 fraction. It may also be noted that by means of very rigorous gravity separation involving large reject losses, the percentages of vitrain were raised to 15.7, 28.7, and 57.9 respectively for the three size

fractions. Although the vitrain content of the float 8-mesh by 0 fraction attains the high value of approximately 58 percent, the actual amount of vitrain present is only about 1 percent of the 1½-inch sample and is accomplished by a very high degree of selective concentration.

It will doubtless be observed that the vitrain content of the 7/16-inch by 10-mesh stoker coal is somewhat higher than either the ½-inch by 8-mesh or the 8-mesh by 0 fractions, which combined have a vitrain content of 20.1 percent. An analysis of the distribution of the vitrain in the various sizes of these two coals given in the two size-frequency distribution tables (Table 5) and Figure 10, together with the figures on vitrain content in the 8 by 48-mesh coal derived from 1½-inch screenings, provides an explanation for the higher content of vitrain in the prepared stoker coal. The 8 by 48-mesh fraction is essentially a dedusted coal, and it is apparent that the minus 48-mesh dust contained a considerably smaller proportion of vitrain than the 8 by 48-mesh fraction, in view of the increase in the vitrain content as a result of the elimination of the dust. Accordingly it is to be expected that the percentage of vitrain in the various screen fractions will decrease in the finer screen fractions. Thus in the ½-inch raw screenings, the maximum percentage of vitrain is contained in the 20 by 28-mesh fraction; and in the 7/16-inch by 10-mesh coal it is in the sizes 14 by 48-mesh, decreasing rapidly below in both coals.

It is apparent that the quantity of vitrain in the 1½-inch screenings is about 5 percent in excess of the proportion of this ingredient in the bed coal, as determined by column measurement. It is also apparent that this concentration is contained in the sizes ½-inch by 48-mesh. In the sizes 1½-inch by ½-inch and in the minus 48-mesh fines there is less proportional vitrain than in the bed coal. The percentage of vitrain in sizes ½-inch by 48-mesh is, by calculation, about 21 percent. It is probable that additional cleaning would raise the vitrain content in this size to approximate that of the 7/16-inch by 10-mesh mine prepared coal.

The relatively low concentration of vitrain in the improved coals used in the stoker tests, and studies of the vitrain content of specially prepared coals described above suggested the advisability of investigations into the extent and character of concentration of banded ingredients produced by float-and-sink separation. The procedure and results of such tests are described in the section on Float-and-Sink Separation.

INGREDIENT DISTRIBUTION IN SMALL SIZES OF BROKEN INGREDIENTS AND WHOLE COAL.

In the present exploration of the character of breakage of the banded ingredients of Illinois coals and the size-frequency distribution obtained, the studies sought to determine whether or not hand-picked ingredients broke similarly to coal as a whole, and whether or not the character of the breakage favored segregation of any of the ingredients in any of the screen sizes when subjected to screen separation. The manner of use of the results of the investigation in arriving at estimates of the composition of broken coal in terms of the ingredients is explained below.

Size-Frequency Distribution of Banded Ingredients and of Whole Coal.—Screen analysis was made of four varieties of coal: (1) Hand-picked vitrain, clarain, and durain (Table 3, Fig. 13); two natural coals, (2) 1½-inch by ½-inch and (3) ½-inch by 8-mesh, respectively, all being crushed mechanically or by hand to pass an 8-mesh screen; and (4) for special comparison, a sample of coal of minus 8-mesh size obtained from the undersize coals screened out of one of the samples brought to the laboratory for combustion tests.

It is apparent from a scrutiny of the data (Table 3, columns 1 to 7, and Fig. 11) that in spite of the known difference in the hardness of vitrain, clarain, and durain, the same conditions of crushing yield a similar pattern of size distribution. Furthermore, it is apparent that this pattern of size distribution is also shared in a general way by all the other coals tested.

General Law of Size Composition of Broken Coal.—The size composition of broken coal has been extensively investigated by coal research organizations, one notable contribution being the development by Rosin and Rammler [14] of an equation relating the percentage of coal retained on a test sieve to the size of the openings in the sieve. M. R. Geer and H. F. Yancey of the U. S. Bureau of Mines tested the applicability of Rosin and Rammler's law for expressing the size composition of a variety of broken coals of both coarse and fine sizes. They prepared a specially ruled graph paper by using the equation as modified by Bennett [15] to plot cumulative weight percent against screen size for a large number of screen analyses. When the size distribution of a crushed material conforms with Rosin and Rammler's law, the cumulative percentage data from screen analysis when plotted on this form of graph will show a straight line relationship (Fig. 11).

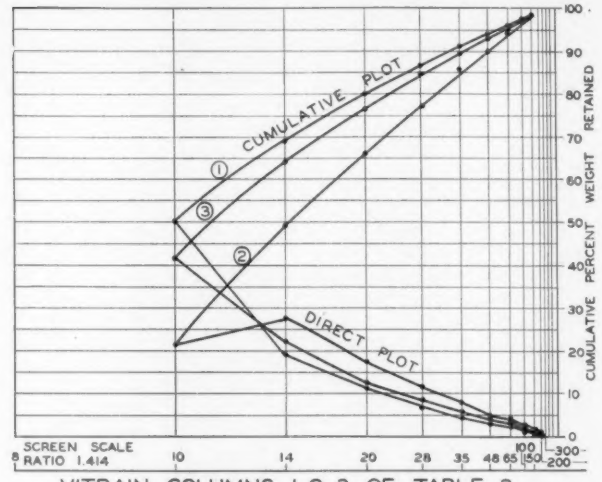
Application of the Rosin and Rammler Law to the Immediate Size-Distribution Data.—Upon the special graph form, prepared in accordance with the specifications of Geer and Yancey, the screen analysis data (Table 3) were plotted for the various coals used in this special investigation. It is apparent that the hand-picked banded ingredients as well as the mixed coal samples produce essentially straight lines (Fig. 13) and hence that the size-frequency distribution conforms with the Rosin and Rammler law. The greatest amount of variation from a straight line for any coal is found near the top size, that is the 8 by 10-mesh size. This phenomenon was noted and explained by Geer and Yancey as a peculiar attribute of the Rosin and Rammler equation which they state does not describe accurately the distribution of the coarsest particles.[16]

A deviation from a straight line also may be observed for the three finest screen sizes for every coal. This, however, is of little significance. A careful examination of the graphs will reveal that no plotted point is more than 0.5 percent removed from the straight line. Therefore, although the

[14] Rosin, P., and Rammler, E., Laws covering the fineness of powdered coal: Inst. Fuel Jour., vol. 7, pp. 29–36, 1933.

[15] Geer, M. R., and Yancey, H. F., Expression and interpretation of the size composition of coal: A.I.M.E. Trans., vol. 130, pp. 250–269, 1938. Bennett, J. G., Broken coal: Inst. Fuel Jour., vol. 10, pp. 22–39, October, 1936.

[16] Geer, M. R., and Yancey, H. F., op. cit., p. 257.



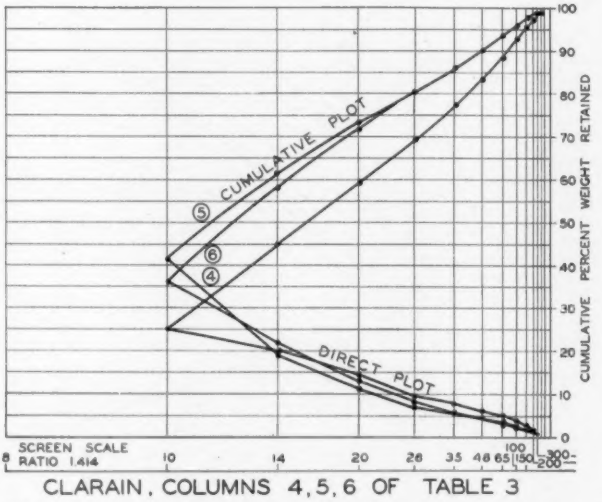
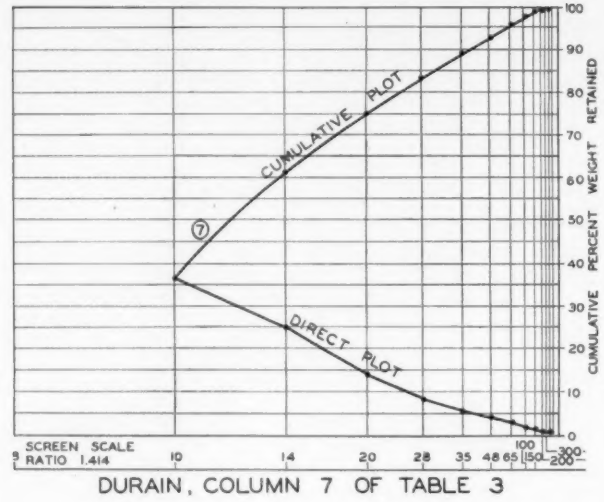


FIG. 11a. Cumulative and direct plotting of screen analysis data (Table 3) with horizontal scale in same ratio as that of the standard scale sieves.



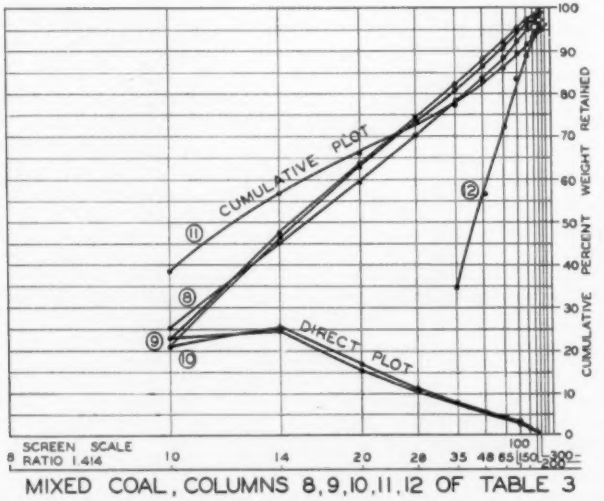
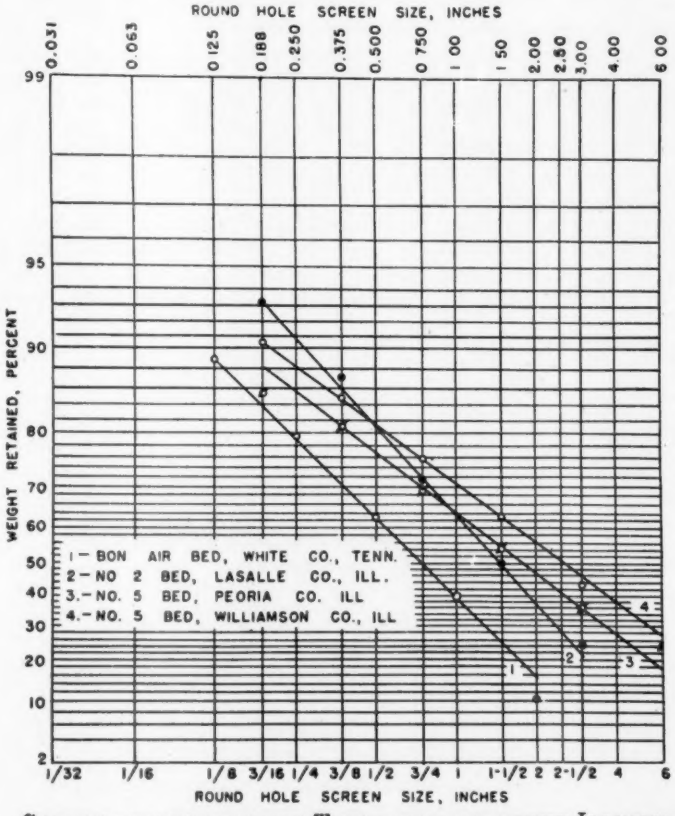


FIG. 11b (continued). Cumulative and direct plotting of screen analysis data (Table 3) with horizontal scale in same ratio as that of the standard scale sieves.

equation does not seem to describe quite adequately the size distribution in the finest grade sizes, the relatively small degree of departure percentagewise does not invalidate the usefulness of the curves as a picture of size distribution of broken particles of coal or of the coal ingredients.



SCREEN ANALYSES OF ONE TENNESSEE AND THREE ILLINOIS COALS.

FIG. 12. (M. R. Geer and H. F. Yancey, A.I.M.E. Trans., vol. 130, fig. 1, p. 253, 1938.)

Comparison of Size-Distribution of Vitrain in Broken Coal and of Crushed Hand-Picked Vitrain.—The validity of the conclusion reached in regard to the size distribution of vitrain in broken coal is supported by a comparison of the distribution of vitrain in the various sizes of broken mixed coal and

of crushed hand-picked vitrain (Fig. 13 and Table 3, column 13). The percent distribution of the vitrain in the crushed sample of mixed coal as determined petrographically is in agreement with the size distribution of the ingredient in "pure" form when all the coal is crushed in the same manner. This similarity of distribution is the basis for the method employed in determining the vitrain content of the finer screen sizes into which the samples are subdivided preparatory to petrographic analysis.

Significance of Size Distribution as Applied to Banded Ingredients.—The exploration of the nature of breakage of mixed coal and of hand-picked ingredients by laboratory tests led to the discovery that all components as a whole generally conform to a common law of size distribution. It also indicated that there had been little or no differential breakage to produce segregation of certain of the banded ingredients in the different screen sizes, except possibly in the very fine sizes.

These tests therefore indicate that in general, when coal is broken down from the bed in mining operations, differential breakage of the banded ingredients is not nearly so complete as has been supposed, except possibly as regards fusain. Consideration of the character of the material will show why this is so. Vitrain and durain rarely exceed ½-inch in thickness and hence rarely exist as discrete coarse size fragments greater than ½-inch in diameter. On the contrary, they are commonly found in large lumps of coal that consist predominantly of clarain, and the dominant ingredient of any size category of broken coal (excepting the small sizes below 28-mesh) is clarain. It is only when the coal is subjected to complete crushing below 8-mesh (1/10-inch) that the three ingredients are recognizable to any extent as discrete entities. Consequently, the size distribution pattern of naturally broken coal is the pattern of clarain. Where mining breakage, preferential or otherwise, exposes vitrain, its marked brittleness subjects the ingredient to some differential reduction, which may account for a certain degree of concentration mainly in 8 by 48-mesh sizes. However, the impression that certain small sizes, mainly in minus 1¼-inch screenings, consist predominantly of vitrain is erroneous and is probably owing to identification of bright clarain as vitrain. As most Illinois coals consist predominantly of bright clarain, it is to be expected that the fine coal will be mostly bright. In these fine sizes the differentiation of vitrain and bright clarain is difficult and requires considerable care. It is only in the very fine sizes that liberated microvitrain begins to appear in appreciable quantity.

In the mining and the subsequent handling of coal during preparation, the forces which break up coal into lumps and small fragments are not continuously applied but are variable and accidental unless some of the coal is crushed mechanically. This results in a random breakage, often called natural breakage, but whether or not it is selective in reference to the banded ingredients other than fusain is not conclusively known. In the light of present information the absence of any appreciable degree of differential concentration of clarain, vitrain, and durain in a broken coal product such as screenings may be attributed to the following factors: (1) The tendency of the ingredients, regardless of how broken, to reduce in size and conformity

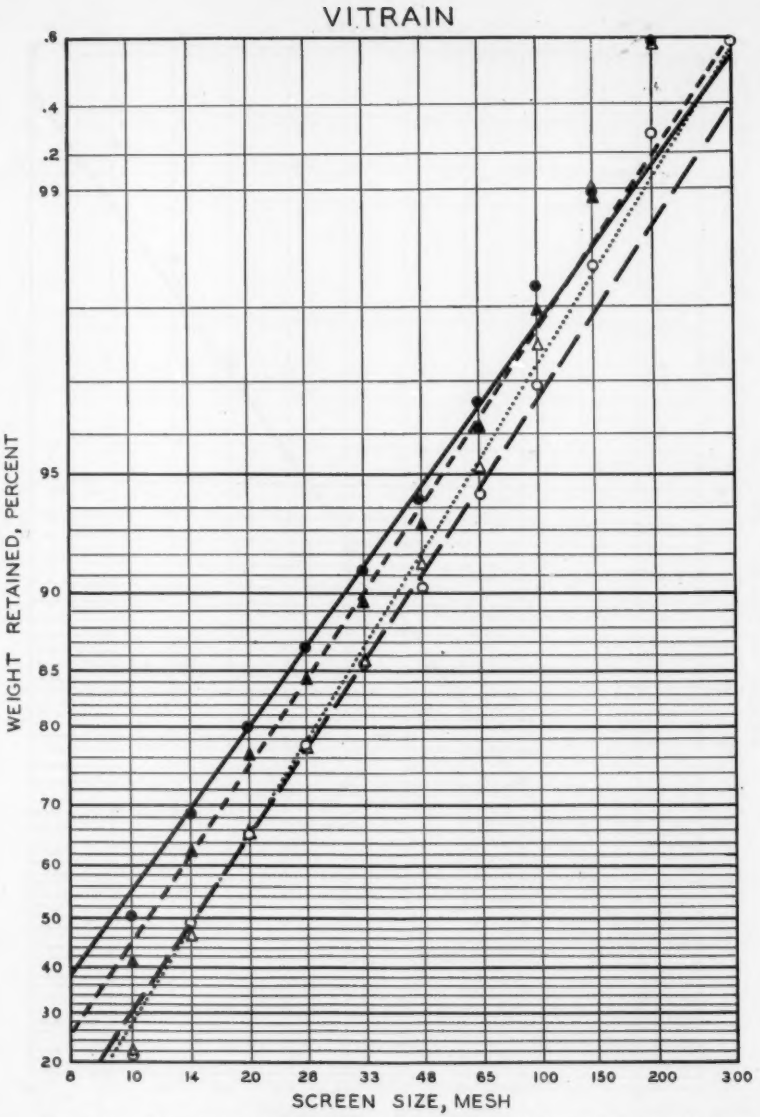


FIG. 13a. Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 1, table 3, p. 385. Open circle = column 2, table 3, p. 385. Solid triangle = column 3, table 3, p. 385. Open triangle = column 13, table 3, p. 385.

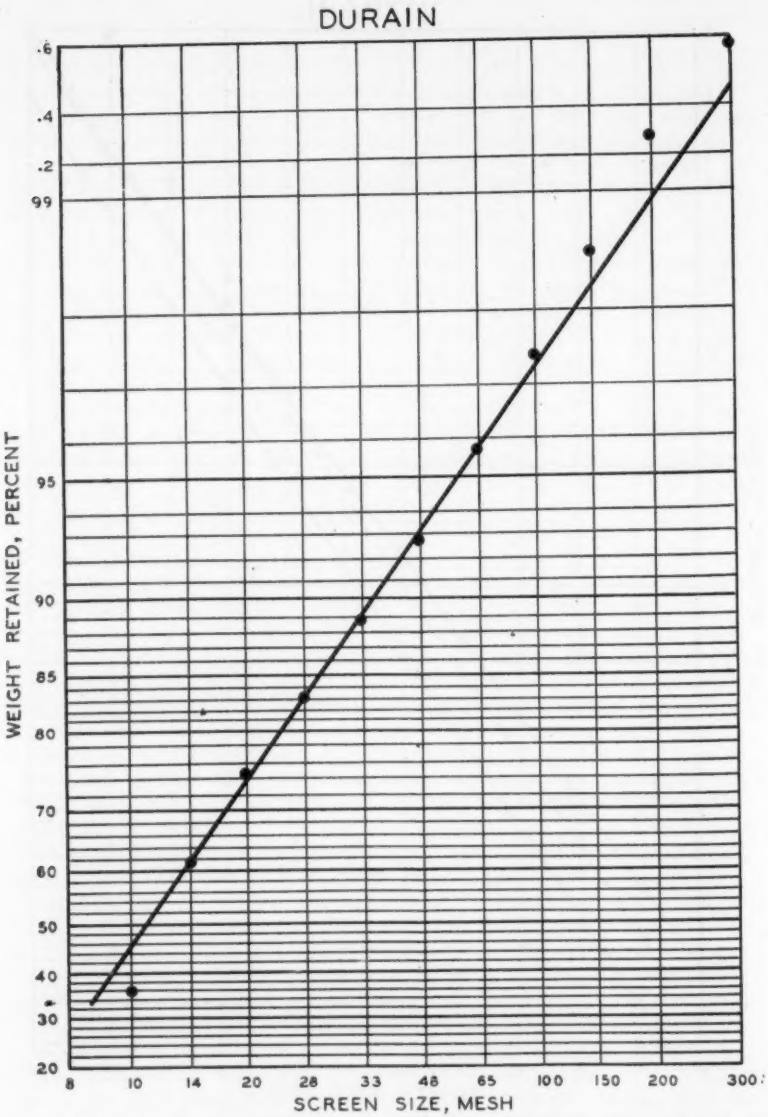


FIG. 13b (continued). Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 7, table 3, p. 385.

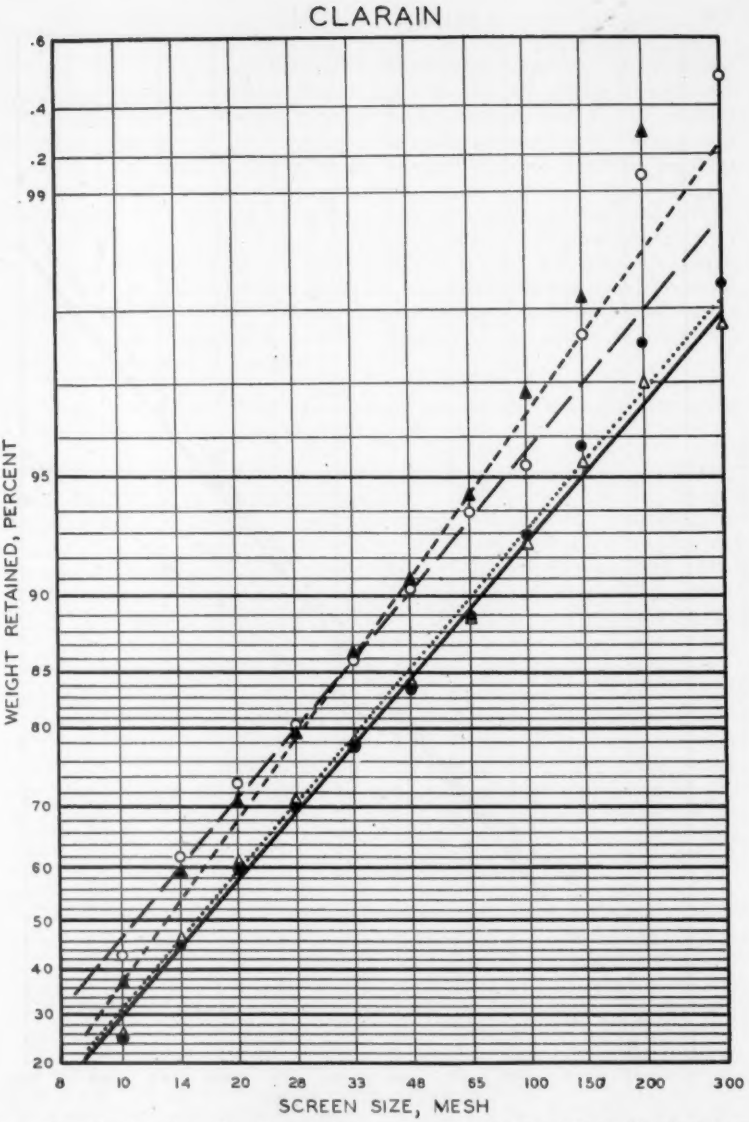


FIG. 13c (continued). Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 4, table 3, p. 385. Open circle = column 5, table 3, p. 385. Solid triangle = column 6, table 3, p. 385. Open triangle = column 8, table 3, p. 385.

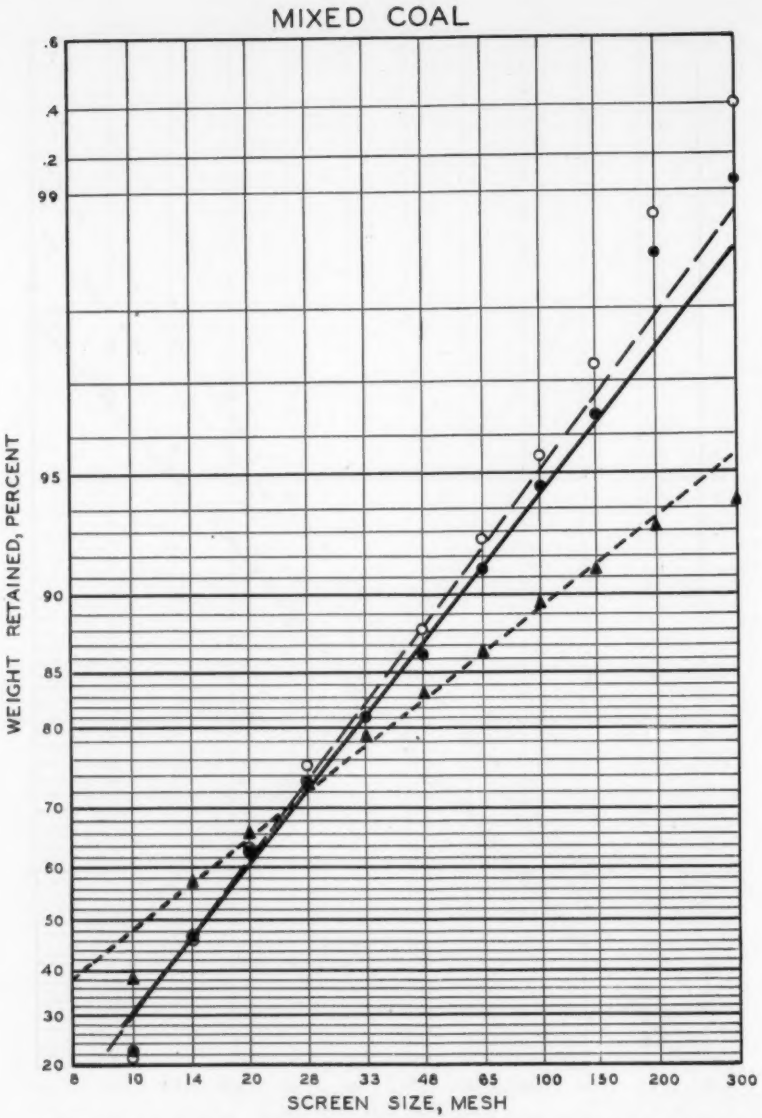


FIG. 13d (continued). Cumulative screen analysis data (Table 3) plotted on special form of graph paper prepared in accordance with Rosin and Rammler's equation expressing size distribution of broken coal. Solid dot = column 9, table 3, p. 385. Open circle = column 10, table 3, p. 385. Solid triangle = column 11, table 3, p. 385.

with the law of size reduction of uniformly brittle substance; (2) the relatively small amount of durain and vitrain (the two ingredients at extremes of hardness) and the thinness of these bands compared with clarain prevent important influence in coal breakage; (3) the amount of differential size reduction from abrasion and grinding of ingredients of different hardness is probably small because of the disproportionate amounts present and the discontinuous nature of the forces breaking coal in mining operations; (4) in natural breakage (mining and preparation exclusive of mechanical crushing) less than 5 per cent of the bed coal is reduced to small particle sizes (minus 8-mesh or 1/10-inch), and tests indicate a vitrain content less than 30 percent. Although this figure may be percentagewise more than twice the vitrain value in the bed coal, on a properly weighted basis, obviously very little excess concentration is possible.

EXPERIMENTAL TESTS IN FLOAT-AND-SINK SEPARATION FOR CONCENTRATING THE BANDED INGREDIENTS.

Nature of Specific Gravity of Coal.—Coal, as a porous solid substance, gives two limiting values for specific gravity. The larger value, and the true specific gravity, pertains to the coal substance and its included mineral matter less all voids; the smaller value, an apparent specific gravity, corresponds to the solid substance including the pore-spaces. The specific gravity of a lump of coal varies as the proportion of air and moisture changes in the pore-spaces. In consideration of this variability, the term "apparent specific gravity" is commonly applied to coal, and loss of moisture by drying is recognized as the most important factor in altering the apparent specific gravity.

Coal in the bed before mining is generally considered to be saturated with moisture, and if no gas is included in the pore-spaces the coal is considered near its maximum specific gravity value. Reduction of the coal to lump and smaller sizes and exposure to air during mining and handling causes changes whereby every particle of coal has a different apparent specific gravity. If any particular fragment of coal is considered, its apparent weight at any specified time depends upon the atmospheric conditions which surround it, and the weight varies between the limits of a dry and those of a saturated condition.

Close approximations to the limiting specific gravity values can be obtained for a fragment of coal by the use of a Westphal balance or similar instrument by weighing the coal air-dry, instantly under water, and again under water when the coal has become completely saturated. These three weighings permit the determination of an initial apparent specific gravity (dry basis) and a final value (saturated basis).

There are three inherent factors important in predetermining the apparent specific gravity of a particle of coal: The real specific gravity of the coal substance itself, the mineral matter content, and the porosity. It is generally conceded that vitrain is usually lower in mineral matter (ash) and higher in porosity than the other coal ingredients. Therefore in a dry condition it should be the lightest, followed in order by clarain, durain, and fusain.

It is logical to assume that the differences in apparent specific gravities of the banded ingredients (moisture-free condition) can be used to separate these components from a mixed sample by using heavy liquids. Our laboratory experiments have proved that this can be done under carefully controlled conditions.

There is a fourth factor, size of the coal particle, although not fully evaluated, which may also affect the apparent specific gravities of broken coal. The apparent specific gravity tends to increase with decreasing size of particle. A fragment of vitrain of 10 grams weight, dry basis, that will just float on a fluid of 1.250 specific gravity, when broken down into particles all much smaller than the original lump, will not float completely on the same fluid. There may be several reasons for this behavior. The larger fragments may contain air pockets in incipient fractures, giving greater buoyancy, and many have a lower ratio of mineral matter to coal and pore-spaces because of the unequal dissemination of mineral matter in the coal. Also, as the ratio of surface to volume is greater for small particles than for larger, the rate of saturation of the immersion fluid in the former may be considerably greater. In the case of durain, which is wholly attrital in nature, and of clarain, which is partly so, the difference in specific gravities of the disseminated botanical components may also affect the apparent specific gravity of the smaller particles of these coal ingredients.

Methods and Results of Experimental Tests.—The preceding explanation of the nature of the specific gravity of coal indicates the dependence upon the extent of moisture saturation of results obtained in gravity separation of the banded ingredients. The tests demonstrated this dependence and also help to explain some of the phenomena of separation and concentration of the ingredients. The tests consisted of the determination, first, of the comparative specific gravity of the individual ingredients on an air-dried basis, and second of determinations of specific gravity for successive stages of saturation from dryness to complete saturation. The results of gravity separation tests on a set of raw screenings also demonstrate some of the phenomena of ingredient separation and concentration.

Twenty-one pieces of coal ingredients weighing from 2.2 to 8.4 grams (Table 10), equally divided among vitrain, clarain, and durain, were carefully selected for purity. The specific gravity of each fragment was obtained by using a Westphal balance in the following manner. The small lump of coal having been dried to constant weight in air was then quickly weighed in distilled water. From the two weighings in air and in water the apparent specific gravity was computed with the formula of the usual type, $D = W/W - ws$. The coal was left submerged in the water until a constant weight of saturation was reached, with weights being taken at regular intervals. The accumulated data, when plotted on a graph, showed change in the weight of the coal fragment soaked in water per unit of elapsed time.

The initial specific gravities of all specimens of vitrain (Table 10, column 1) were found to be lower than those of clarain, but with only slight difference between the heaviest vitrain and the lightest clarain specimen. Had a larger number of pieces of each material been used no doubt actual overlap would

TABLE 10.

VARIATION IN APPARENT SPECIFIC GRAVITY WITH CHANGES IN MOISTURE CONTENT OF SELECTED SAMPLES OF VITRAIN, CLARAIN, AND DURAIN AS ARRANGED IN ORDER OF INCREASING SPECIFIC GRAVITY.

(1)		(2)		(3)		(4)	
Initial sp. gr.	Air dry	Soak 30 min. in H_2O		Soak 1 hr. in H_2O		Saturated condition	
gms	sp. gr.	gms	sp. gr.	gms	sp. gr.	gms	sp. gr.
V 2.198	1.131	V 2.198	1.212	V 5.550	1.235	V 5.550	1.319
V 2.553	1.164	V 5.550	1.219	V 2.198	1.242	C 6.257	1.333
V 2.115	1.176	V 4.715	1.224	V 2.553	1.247	C 8.367	1.340
V 5.550	1.176	V 3.377	1.238	V 3.377	1.257	C 5.755	1.342
V 3.377	1.187	V 4.715	1.244	V 4.715	1.262	V 4.715	1.347
V 2.940	1.195	C 5.118	1.260	C 5.118	1.279	C 5.907	1.351
V 4.715	1.200	C 5.216	1.261	C 6.257	1.282	D 5.977	1.355
C 5.216	1.204	C 6.257	1.262	C 5.216	1.289	V 2.115	1.365
C 5.755	1.206	C 2.580	1.268	C 5.755	1.291	V 3.377	1.368
C 8.367	1.213	C 8.367	1.268	C 8.367	1.291	D 5.014	1.368
C 5.907	1.215	V 2.940	1.270	V 2.115	1.303	D 5.282	1.377
C 5.118	1.218	C 5.755	1.272	C 5.907	1.318	D 3.087	1.380
C 6.257	1.221	C 5.907	1.276	V 2.940	1.321	D 2.267	1.385
C 2.580	1.223	V 2.115	1.277	D 5.977	1.327	D 6.650	1.385
D 5.282	1.275	D 5.977	1.322	C 2.580	1.330	D 6.810	1 386
D 6.810	1.290	D 5.282	1.325	D 5.014	1.332	V 2.940	1.410
D 6.650	1.293	D 5.014	1.325	D 5.282	1.338		
D 5.014	1.298	D 6.810	1.330	D 6.810	1.339		
D 5.977	1.299	D 3.087	1.332	D 2.267	1.342		
D 3.087	1.304	D 6.650	1.335	D 6.650	1.342		
D 2.267	1.309	D 2.267	1.336	D 3.087	1.343		

(1a)		(2b)		(3c)		(4d)	
Av. sp. gr.	Diff. from Vitrain	Av. sp. gr.	Diff. from Vitrain	Av. sp. gr.	Diff. from Vitrain	Sp. gr.	Diff. from Vitrain
V 1.175	—	1.241	—	1.267	—	1.362	—
C 1.214	3.3%	1.267	2.1%	1 287	1.6%	1.342	−1.5%
D 1.295	10.2%	1.329	7.1%	1.338	5.6%	1.377	1.1%

The increase in specific gravity of 4d over 1a is 15.9 percent for vitrain, 10.5 percent for clarain, and 6.3 percent for durain.

have been realized. The lighest particle of durain is at a considerable spread from the heaviest piece of clarain, so that the probability of actual overlap is less definitely indicated. The range of initial specific gravities for the vitrain specimens is considerably greater than for the other two ingredients, a relationship which indicates greater porosity. This is also indicated by the summary data which shows the percentage of increase in specific gravity of the three ingredients as saturation advanced, vitrain increase being 15.9 percent, clarain 10.5 percent, and durain 6.3 percent. These figures must be regarded as indices of relative porosity. The obvious conclusion is that the fundamental coal material, irrespective of the mineral matter, has about

the same specific gravity. Whether or not this is true of special concentrations of such constituents of the clarain and durain as plant spores, resins, cuticles, remains to be investigated. Fusain is probably in a category by itself, because its relative buoyancy is determined primarily by its very porous structure, a condition unrelated to internal texture which may or may not be porous. Because of its high carbon content, it is suspected that fusain has a relatively high true specific gravity, approaching that of anthracite.

Further study of the gravity data was made to determine the theoretical maximum concentration of the ingredients that might be expected under extreme conditions of separation, such as are rarely employed in practice. This would give some idea of the possibility of gravity concentration. Simple calculations showed that if a separation fluid were used of such a gravity that approximately one-fourth by weight of the coal floated (column 4, Table 10), then 27.5 percent of the float would be vitrain and 72.5 percent clarain, with no durain present. However, only 30 percent of the total amount of vitrain in column 5 would collect in the float. If the specific gravity of the fluid were increased so that approximately 50 percent of the coal floated, then the proportional distribution in the float would be 24.1 percent vitrain, 61.8 percent clarain, and 14.1 percent durain, with 54.9 percent of the total vitrain collecting in the float. These figures give some idea of the extent of concentration of the ingredients that might be expected under conditions of definitely isolated discrete fragments of fairly large size.

To determine whether or not these characteristics apply to a more or less heterogeneous mixture of coal, a large sample of raw (1½-inch by 0) Franklin County screenings was subjected to float-and-sink separation. The tests were designed to explore the effect of variations in the specific gravity of the separation fluid upon the vitrain content of the coal. The sample was sized in the laboratory by screening into four categories: 1½-inch by ½-inch, ½-inch by 8-mesh, 8-mesh by 0, and 8 by 48-mesh (Table 11). The vitrain content of each size was determined (column 3).

The lightest 24 percent of the 1½- by ½-inch was separated by manipulation of the gravity of separating fluid. This float material was found to contain 15.7 percent vitrain, or 21.6 percent proportionally more than was present in the original sample (12.3 percent). Of the total vitrain in the 1½ by ½-inch coal, 30.7 percent concentrated in this float. This proportion is essentially the same as that derived theoretically from the data provided by the tests on the manually separated banded ingredients. The fragments were relatively large, and because they had been stored in a sealed container, it is believed that they were fairly well saturated with mine moisture.

In the second size fraction, ½-inch by 8-mesh, the float, representing approximately 24 percent, contained 28.7 percent vitrain, an increase of 55 percent. The increase of vitrain percentage is rather impressive, but of the total amount of vitrain in the immersed sample only 38.3 percent was concentrated in the float. Agreement with the theoretical percentage is not as close as it was for the larger coal but is still of the same general order of magnitude, suggesting at least approximate validity.

In the 8-mesh by 0 size coal, separation was made at an extremely low gravity so that only the lightest 12 per cent of the sample was recovered. This coal showed a very sizable increase in vitrain content (57.9 percent). But even this recovery represented only 27 percent of the vitrain in the immersed sample.

The 8 by 48-mesh coal was so floated that 53 percent was recovered, containing 39.2 percent vitrain, or 71 percent of the total vitrain content of the immersed coal.

TABLE 11.

VITRAIN CONTENT OF 4 SCREEN-SIZE FRACTIONS OF A SAMPLE OF 1½-INCH RAW SCREENINGS AND OF 8 FLOAT-AND-SINK PRODUCTS OF THESE SIZE FRACTIONS.

	(1) Size fraction	(2) Percent of sample	(3) Vitrain percent	(4) Lightest 24% of A (1) floating at 1.285 sp. gr.	(5) Heaviest 76% of A (1) sinking at 1.285 sp. gr.	(6) Percent of total vitrain col. 3 in float col. 4	(7) Percent of total vitrain col. 3 in sink col. 5
A	1½″×½″	52.5	12.3	15.7% vitrain	11.3% vitrain	30.7% vitrain	69.3% vitrain
				Lightest 24% of B (1) floating at 1.281 sp. gr.	Heaviest 76% of B (1) sinking at 1.281 sp. gr.		
B	½″×8-mesh	34.3	18.0	28.7% vitrain	16.0% vitrain	38.3% vitrain	61.7% vitrain
				Lightest 12% of C (1) floating at 1.285 sp. gr.	Heaviest 88% of C (1) sinking at 1.285 sp. gr.		
C	8-mesh×0	13.2	25.9	57.9% vitrain	21.7% vitrain	26.8% vitrain	73.2% vitrain
				Lightest 53% of D (1) floating at 1.296 sp. gr.	Heaviest 47% of D (1) sinking at 1.296 sp. gr.		
D	8×48-mesh	10.2	29.5	39.2% vitrain	18.3% vitrain	70.8% vitrain	29.2% vitrain

It is apparent that one of the two finer sizes of coal, and probably both, show a vitrain recovery considerably above the theoretical possible recovery of about 30 percent and above that of the two coarser coals. The 8 by 48-mesh coal is essentially a dedusted coal, the fusain having been largely removed, so that the content of vitrain is above that which was recovered in the 8-mesh by 0 size. Furthermore, in both minus 8-mesh samples the amount of analytical vitrain was probably increased somewhat by the presence of more or less microvitrain derived from broken clarain. The clarain that remained would therefore tend to be somewhat heavier. But the chief consideration may well be that, because of the fineness, the material was more susceptible to moisture change, so that it acquired in handling a more or less air-dried condition by the time the float-and-sink procedure was applied. This seems to be the only reasonable explanation of the phenomenon of greater recovery of vitrain from the fine sizes of coal.

Suggestions Relative to the Concentration of Banded Ingredients.—From the preceding studies it is apparent that for effecting a concentration of the discrete particles of banded ingredients of the coals used in these tests, the first requirement is the mechanical crushing of the coal to a size dimension less than 1/10-inch. The specific top size depends upon the dimensional criterion adopted for delimiting the banded ingredients, particularly vitrain. If megascopic dimension for classification is used, size reduction cannot exceed a top size of about 0.02-inch. Whatever top size is accepted, crushing should be done in such a way as to produce maximum liberation of the ingredients with a minimum of extremely fine sizes.

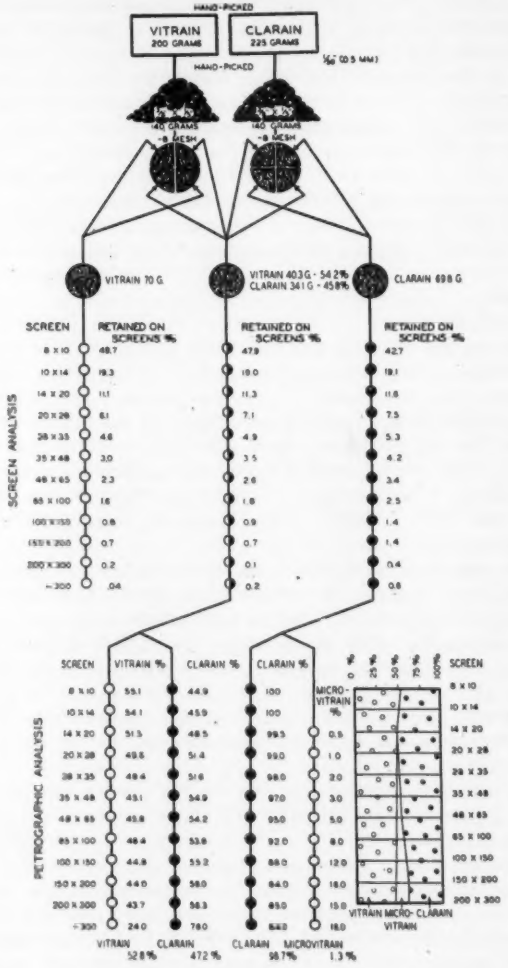
On the basis of tests demonstrating marked differences in the apparent specific gravities (dry basis) of the banded ingredients (Table 10), float-and-sink gravity separation is probably the best way to isolate the banded ingredients. Laboratory trial tests may be necessary to determine how to adjust the density of the fluid to obtain a float product containing a predominant amount of the desired ingredient. It is unlikely that a completely strict isolation of an individual ingredient can be obtained in this manner, but it seems reasonable to predict that float products can be secured containing a high concentration of such an ingredient. This has been done repeatedly in our laboratory with small samples. However, it is believed that a high order of ingredient concentration can be secured only by preparation of the coal by complete crushing to liberate the ingredients, followed by drying to bring out their maximum variation in apparent specific gravity, and by rapid separation by some form of gravity concentration. This does not preclude the possibility that methods of mining and preparing coal, other than those used in the production of the coals which were the subject of the present studies, might cause a different manner and degree of segregation of the ingredients. The possibilities of such variation have not been systematically canvassed, and further investigation is desirable.

EXPERIMENTAL COMPARISON OF PERCENTAGE ESTIMATES DERIVED BY MICROSCOPIC COUNT WITH KNOWN WEIGHT PERCENTAGES OF A MIXED SAMPLE OF VITRAIN AND CLARAIN.

It seemed advisable to compare percentage estimations obtained by petrographic analysis with the actual weight percentages of the hand-picked banded ingredients in specially prepared samples (Fig. 14).

Method and Results.—For this experiment, two blocks of hand-picked vitrain and clarain were obtained, each weighing about 200 grams. The clarain was a very finely striated variety in which the microvitrain bands were less than 0.5 mm (1/50-inch) in thickness. The specimens of vitrain and clarain were broken up separately into fragments of about ⅜ by 1/5-inch dimension and then carefully repicked to procure samples of each type that were megascopically pure. Each batch was then crushed carefully with mortar and pestle to pass an 8-mesh screen.

In preparing the sample for the microscopic count, 40.3 grams of vitrain (54.2 percent) and 34.1 grams of clarain (45.8 percent) were riffled out and



PETROGRAPHIC ANALYSIS OF A SPECIALLY PREPARED MIXED SAMPLE OF VITRAIN AND CLARAIN

FIG. 14. Diagrammatic presentation of analyses by screen sizes of hand-picked clarain and vitrain and of a mixture of the two.

thoroughly mixed. For the purpose of comparison, concurrent screen analyses were also made, using vitrain and clarain as prepared before mixing. The three screen analyses of vitrain, clarain, and the vitrain-clarain mixture are shown by the diagram (Fig. 14). It may be noted that the weight percentages retained on each screen of the vitrain-clarain mixture are intermediate between the values for the same screens for vitrain and clarain. Probably more than anything else this fact may indicate uniformity of sizing of the ingredients in both the mixed and pure samples when screened.

The microscopic assay of the vitrain-clarain mixture gave 52.8 percent vitrain and 47.2 percent clarain. These values represent an increase of 1.4 percentage points for clarain with a corresponding decrease of 1.4 percentage points for vitrain over the percentages by weight of these ingredients as mixed in the sample.

If a maximum amount of care was used in identifying and counting the coal particles in this test, the only reasonable explanation for the discrepancy in the percentage values lies in the possibility of differences in specific gravity of the vitrain and clarain used in the experiment. The percentage values which are obtained in the counting procedure are essentially volumetric estimations, and the conversion to weight percentages with screen analysis data assumes the same relative weight and volume relationship for clarain and vitrain particles. Screen analyses of the two pure ingredients classified them essentially alike with respect to size, leaving the weight relationship as the greatest uncertainty.

The best approach toward measuring the relative weights of particles of the vitrain and clarain of the same size seemed to be by actually counting and weighing a large number of particles from the same screen size of each of the reserve samples. This was done, and a total of 4,427 particles of vitrain representing 85 percent by weight of the screen size 8 by 10-mesh were counted and the average per particle weight computed to be 0.00678 gram. For the clarain, 3,054 particles were counted, representing 65 percent by weight of the screen size 8 by 10-mesh, and the per particle weight found to be 0.00637 gram.

If it be taken for granted that the weight relationship between vitrain and clarain as here determined will hold independently of particle size, then a correction of the microscopic count values to equivalent weight percentages can be made by simple arithmetic. To illustrate, let 1,000 represent the total number of all particles counted in the mixed sample to obtain the original microscopic count percentages. Then 528 ($1{,}000 \times 0.528$) of the particles counted were vitrain and 472 ($1{,}000 \times 0.472$) were clarain. Multiplying these numbers by the determined average particle weight of each ingredient (528×0.00678), (472×0.00637) gives 35.8 grams of vitrain and 30.1 grams of clarain, which is 54.3 percent and 45.7 percent respectively of each. These are essentially the weight percentage values of the vitrain and clarain which were combined to form the mixture.

The assumption that coal particles of like size have the same weight regardless of type of ingredient is necessary in order to convert count percentages to weight percentages, but it is evidently a source of some error.

Such an error is probably small, however, so that for practical purposes the assumption is still useful. The greater relative heaviness of the vitrain used in this experiment is probably unusual, for clarain is considered to be generally heavier than vitrain. Their difference in real specific gravity is primarily attributed to a higher ash content which clarain most often has because of its attrital composition. However, there is no fundamental reason why the mineral content of vitrain occasionally might not be such as to give it a greater relative heaviness than associated clarain.

Analysis of Microvitrain.—In order to make the experiment more complete, a percentage estimation was made of the analytical vitrain in the reserve sample of clarain. This was done by making a direct count of this material in all of the screen sizes. The result showed that the composition of the crushed clarain comprised particles of analytical vitrain to the amount of 1.3 percent of the whole sample. This raises the question as to whether this percentage of analytical vitrain introduced an error in estimating the vitrain content of the mixed sample. There can be no direct answer because there is no way of knowing how much liberated microvitrain, if any, was included in the analytical vitrain. However, the following test was made. The quantitative amounts of analytical vitrain, as determined for the four coarsest screen sizes in the mixed sample, were plotted on graph paper and the curve was extrapolated. For the remaining seven screen sizes, beginning at minus 28-mesh, the vitrain content was estimated from the curve. . The vitrain content of the sample, as determined in this way, was 52.5 percent as against a value of 52.8 percent obtained by the actual count of every screen size.

Examination of the data pertaining to the amount of analytical vitrain contained in the pure clarain sample, shown in the diagram in the lower right-hand corner of Figure 14, will show that no analytical vitrain was present in the two coarsest sizes, only 0.5 percent in the third, and only 1.0 percent in the fourth. Thus there was practically no analytical vitrain in the four coarsest screen sizes. As the mixed sample was only half clarain, the amount of analytical vitrain derived from the clarain was obviously so small as to be negligible. It follows, therefore, that in extrapolating vitrain values of the mixed sample from the values in the four coarsest sizes, the analytical vitrain derived from the clarain would have essentially no influence in determining the form of the extrapolated curve. Hence the values for vitrain in the fine sizes would essentially be the values for the analytical vitrain actually derived from vitrain and would not include that derived from the microvitrain in the clarain. Therefore the interpolated value (52.5) is, at least theoretically, more accurate than the value derived by counting particles down to the finest sizes (52.8).

Conclusion.—The studies which provided the basis of this discussion were made for the purpose of having reliable information concerning the ingredient composition of the coals used in a series of combustion tests. These tests were planned to explore the correlation between combustion behavior in an underfeed type of domestic stoker and chemical attributes as determined by analyses and laboratory tests and between combustion behavior and the petrographic constitution or type of coal. There was a possibility that the data

obtained might provide relatively easily determined chemical or petrographic criteria for the selection of satisfactory stoker coal. The extent and value of these correlations are discussed elsewhere.[17]

The procedure of petrographic analysis had to be developed and the analyses made while the stoker tests were in progress. Since the technique had not been critically examined, the validity of the procedure had to undergo analysis and the results had to be experimentally substantiated concurrently with the progress of the analytical work. Consequently, exploratory work was restricted very largely to the coals used in, and as prepared for, the stoker tests. The fact that earlier exploratory investigations of Illinois coal found certain fractions of broken coal with much higher vitrain content (50 to 65 percent) was realized, and this realization made it especially important that the technique employed in the present studies and the nature of the coal used should be thoroughly explained. However, the need to keep analytical work reasonably well abreast of the stoker tests made it impossible to expand the investigation into a search of the possible causes of such high percentage of segregation. Now that the technique has been developed it will be possible, and is desirable, to study systematically the effects of various kinds of breakage and coal separation, both in laboratory and in mining practice. By such procedure it will be possible to determine whether or not a high percent of ingredient segregation is possible as a result of mining and preparation practices within the range of practical usefulness.

ILLINOIS STATE GEOLOGICAL SURVEY,
URBANA, ILLINOIS,
March 6, 1949.

[17] Helfinstine, Roy J., and Boley, C. C., op. cit.

DETERMINATION OF REFLECTIVITY OF THE ORE MINERALS.

R. E. FOLINSBEE.

ABSTRACT.

Increasing sensitivity and reliability of the exposure meters used in amateur and professional photography provides a simple and convenient method of measuring the reflectivity of ore minerals. A mineral species has a limited range of light reflecting power, and a determination of the reflection percentage provides a useful, positive aid in identifying minerals in polished section, in the same way that a determination of index of refraction is diagnostic for the nonopaque minerals.

The relative reflecting powers of some 200 high index nonopaque and opaque mineral species, in the Murdoch suite at Harvard University, were determined with a General Electric photographic exposure meter coupled to a metallographic microscope. The values arrived at check very convincingly with those determined by other investigators; the method used by the writer presents a simplified apparatus.

Absolute values of reflection were determined from relative values by assigning a reasonable reflection percentage (54.5 per cent) to a specimen of pyrite used as a comparison standard in all determinations. These absolute values compare well with those available in the literature. There is a definite relation between index of refraction and reflectivity, expressed in the Fresnel equation, and for high index nonopaque minerals, this relation was confirmed by comparing observed values of reflection against known indices of refraction.

Values of reflecting power for the common species of the opaque or nearly opaque native elements, sulphides, sulphosalts, and oxides, commonly classed as the ore minerals, are presented in the form of two tables designed to aid in the rapid determination of these minerals in polished section or in cleavage fragments.

ACKNOWLEDGMENTS.

THE research on this subject was done in the laboratory of mining geology at Harvard University, and received stimulus and direction from Professor L. C. Graton, whose advice and assistance is most gratefully acknowledged. For a background the writer drew upon J. H. Moses' thesis (1),[1] and this work was invaluable as a guide. Some of the results of Moses' work have been published (2), and in part are incorporated in the tables presented in this paper. Good results in determining reflectivity from a polished surface depend to a large extent on the perfection of polish. All specimens were prepared using skillful application of the Harvard method, which minimizes relief by employment of lead laps. The writer is indebted to Mr. Charles Fletcher of the laboratory of mining geology for the interest and care he took in this phase of the investigation.

APPARATUS AND METHOD.

The apparatus is pictured in Figure 1. Light from a G.E. 275 watt tungsten-filament projection bulb housed in a Bausch and Lomb microscope lamp

[1] Numbers in parentheses refer to bibliography at end of paper.

was made to pass through an aspheric condenser, through a Leitz condensing lens with diaphragm, down from a Leitz vertical prism illuminator through a 4 mm objective lens to the specimen held in a self leveling mount, then back up the tube of the microscope. For focusing, and for locating the area for which reflectivity was to be determined, an 8 power periplane ocular was chosen. Intensity of illumination for this examination was reduced by inserting a daylight filter between the condensing lenses.

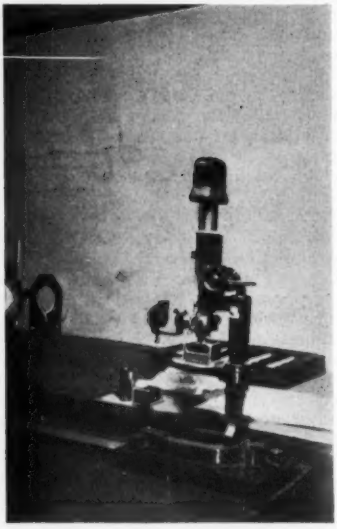


FIG. 1. The reflection apparatus with exposure meter in place.

Using a four millimeter objective lens and an 8 power periplane ocular the field of view, about one millimeter in diameter, was the same as the field projected on the sensitive plate of the exposure meter. The outer shell of the General Electric exposure meter was replaced by a template, arranged so that the meter, with the microscope ocular removed, would securely fit the microscope tube and use invariably the same (circular) area of the photosensitive receiving plate.

To determine the relative reflectivity of a mineral species the following procedure was adopted. First the comparison standard, a well-polished piece of pyrite, was cleaned with zylol, dried, and placed under the objective lens. A scratch-free surface was brought into exact focus. The ocular and daylight filter were removed, the meter replacing the ocular. By means of the diaphragm on the condensing lens the intensity of illumination was adjusted to give a reading of 25 foot candles for pyrite, plus a correction for "flare." [2] The ocular was inserted, the unknown placed under the objective

[2] The "flare" correction arose almost entirely from light reflected off the top of the objective lenses. If the pyrite standard was replaced by a piece of black velvet, the meter reading dropped

TABLE 1.

Mineral	Mean index refraction[a]	Percentage reflection		
		Calculated	Observed	
			Moses polish[b]	Folinsbee polish
Alabandite	2.70	21.1	23.3 G	*22.5*[c] G
Cassiterite	2.04	11.7	*12.9* G	12.0 F
Chromite	2.12	12.7	14.0 F	*14.0* F
Cinnabar	2.98	24.7	*26.4* F	—
Columbite	2.35	16.2	—	*18.5* G
Cuprite	2.85	23.1	27.2 P	*27.7* G
Ferberite	2.40	16.9	*17.9* G	17.2 F
Franklinite	2.36	16.4	18.7 G	*19.0* G
Goethite	2.35[d]	16.2	16.1 F	*15.9* F
Hauerite	2.69	21.0	24.0 F	*23.5* F
Hausmannite	2.30	15.5	*19.6* G	18.3 F
Hematite	2.87	23.3	27.3 F	*27.0* G
Huebnerite	2.24	14.6	16.6 G	*16.4* G
Limonite[e]	2.30	15.5	17.2 G	*17.4* G
Magnetite	2.42[d]	17.2	20.7 G	*21.4* G
Manganite	2.34	16.1	*19.0* F	15.7 P
Orpiment	2.74	21.6	22.0 G	21.8 G
Proustite	2.84	22.9	30.3 F	*29.5* F
Pyrargyrite	2.98	24.7	31.0 G	31.0 G
Quartz	1.55	4.7	—	7.2 G
Realgar	2.57	19.3	*18.8* P	—
Rutile	2.70	21.1	*22.9* G	21.8 F
Scheelite	1.92	9.9	—	*12.0* G
Sphalerite	2.34	16.1	17.7 G	*17.9* G
Wolframite	2.38	16.6	18.1 G	*18.1* G
Wulfenite	2.34	16.1	—	*19.4* G
Wurtzite	2.34	16.1	17.5 G	*17.5* G

[a] For lithium light, λ671.
[b] Polish is reported on an arbitrary basis as good (G), fair (F), or poor (P).
[c] Values used in Figure 2 are italicized.
[d] For sodium light λ589.
[e] A discredited species.

lens, and the best polished surface located. The meter replaced the ocular, and a comparative reflectivity reading was obtained after correcting for flare. The complete determination required less than two minutes. The results presented in this paper represent an average of three or more reflectivity readings on each mineral species treated.

THEORY.

For vertical incident light the reflecting power of a transparent isotropic substance may be expressed by the Fresnel equation:

$$R = \left(\frac{n-1}{n+1}\right)^2,$$

from 28 to 3 foot candles, indicating three foot candles of flare. The origin of this light was confirmed by removing the 4 mm objective; with the objective removed the meter reading became zero. It would be necessary to calibrate each instrument for flare, since the reflectivity of different objective lenses may vary. A treated lens would reduce flare to a minimum.

where R is the reflection percentage, n is the index of refraction of the mineral, and the absorption is assumed to be zero. The formula would apply to reflection from the cleavage surfaces of a mineral species such as diamond. Certain errors arise in applying this formula to polished surfaces of the ore minerals examined in non-vertical light, but their magnitude is not great. Table 1 presents the calculated reflectivity of the ore minerals, as derived by the Fresnel equation from their red light indices (in the case of an anisotropic mineral, mean red light index). For comparison, the observed reflectivities are appended. The results are figured graphically in Figure 2. Observed

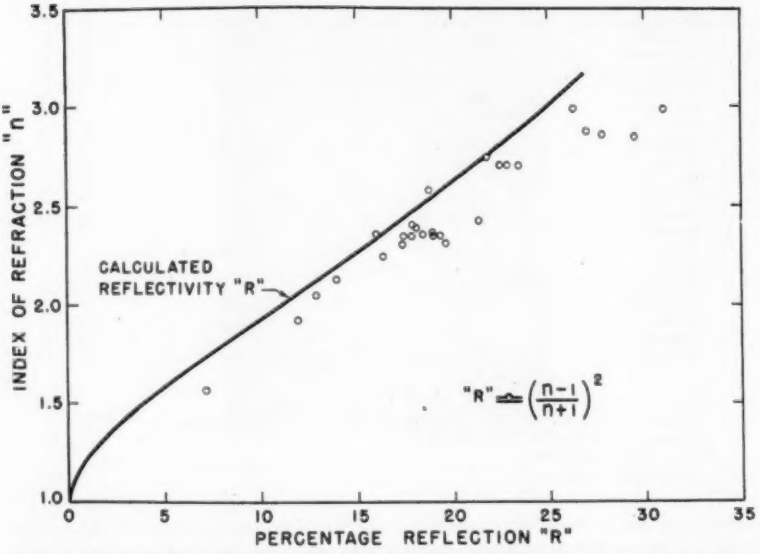


FIG. 2. The relation of the calculated reflectivity curve to observed reflectivities, plotted as circles.

reflectivities lie to the right and below the calculated curve. Two factors account for this apparent discrepancy. The indices used are the only ones available, and are for red light; these indices are lower than the corresponding tungsten filament indices. If tungsten filament indices were available, the observed points which now lie below the calculated curve would be raised an average of 0.1 units on the index scale. This would result in essential correspondence of observed and calculated readings. Secondly, ore minerals absorb a considerable amount of the incident light. A correction for the absorption factor would tend to shift the calculated reflectivity curve to the

right, since with k equal to the index of absorption, the Fresnel equation becomes:

$$R = \frac{(n-1)^2 + n^2k^2}{(n+1)^2 + n^2k^2}.$$

PRINCIPAL VARIABLES IN REFLECTIVITY MEASUREMENTS.

Determination of reflectivity by the method outlined is subject to a number of sources of error. The writer believes that these are, with one exception, insignificant.

1. A light source of constant color quality and intensity is most desirable. To ensure constant color, some investigators have made use of filters in making their measurements (3). Color value of the 275 watt G. E. Mazda projection bulb used in this investigation is held by the maker to be constant throughout its life of about 8 hours. Voltage during measurements fluctuated sufficiently to cause reflectivity readings to vary over a range of plus or minus 3 percent of the mean reading. Taking an average of three or more readings on a mineral, and making frequent checks against the standard, reduced the error due to voltage fluctuations to insignificance. It was not considered necessary to complicate the apparatus by introducing a voltage regulator.

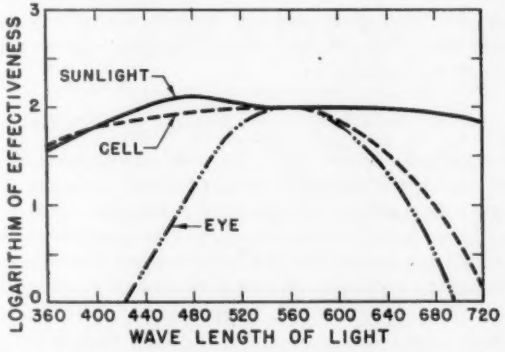


FIG. 3. Color sensitivity of the General Electric photocell and of the human eye, compared with the energy in daylight.

2. A sensitive and reliable light measuring device is provided by using a photographic exposure meter. The General Electric exposure meter was used in this investigation because it had a scale placed conveniently for minimum parallax errors in reading, and because the scale was graduated uniformly. Readings were estimated to a tenth of a division on the scale. The cell has uniform sensitivity over the greater part of the visible spectrum wave lengths; it is slightly insensitive at the red end of the spectrum (Fig. 3). For light sources of lower intensity a Weston Master meter gave good results.

3. The light path was kept constant, and the same light source, lenses, and photocell were used in all readings presented in this paper. Comparable reflectivities were obtained using different light sources, magnification, and photocells.

4. Sharp focusing is obtained by visual operation before taking the photocell reading. The Vogt and Hochesgang microscope was very stable, and focus was not changed by removal of the ocular and positioning of the photocell. The surface of the polished section is kept normal to the axis of the microscope by means of the self leveling mount.

5. For all anisotropic minerals reflectivity will vary with crystal orientation in the polished section. This variable will be significant only for a small group of strongly anisotropic minerals, such as stibnite and covellite; for these minerals the range of reflectivity can be determined.

6. Perfection of polish, cleanliness of the surface, and time since polishing are extremely important variables. Imperfections in polishing, and tarnish, limit the accuracy of the determinations to a greater extent than any other variable. All specimens were polished by the Harvard lead lap method, and an endeavor was made to make readings immediately after polishing was complete to avoid tarnish effects. The importance of these polishing variables, despite the high standard of polish quality in the Harvard laboratory, is readily appreciated when the writer's results are compared with those of Moses (Table 3). For good polished surfaces the average difference in reflection percentage is 0.5 percent. Where imperfect polish is reported, the average difference is 4 percent.

CONVERTING RELATIVE TO ABSOLUTE REFLECTIVITY.

In order to make the results obtained in this investigation more useful for reference purposes it was desirable to express them in terms of percentage reflectivity rather than reflectivity relative to a standard.

In practice it had been found necessary to take a polished mineral surface as a standard, and to compare the reflectivities of all other minerals with it. Pyrite was chosen as a suitable standard, because of its marked uniformity of composition and properties, and its resistance to tarnish. Pyrite from different localities, different age of polish, and even high luster pyrite crystal faces (such as the octahedron 111) were all found to check in reflectivity. In the investigation, pyrite had been assigned an arbitrary reflecting power of 25 foot candles as read on the exposure meter, for comparison with the results of Moses who used an arbitrary reading of 25 galvanometer for this mineral.

Other workers in the field of reflectivity have referred reflecting power to a percentage reflection scale, using various approaches to the problem of standards. To convert the arbitrary readings to percentage reflectivity, the reflecting power of pyrite was considered to be 54.5 percent, and all other readings were adjusted accordingly. This value for pyrite gave the best

TABLE 2.

COMPARISON OF PERCENTAGE REFLECTIVITY DETERMINATIONS.

Mineral	Percentage reflectivity				
	A	B	C	D	E
Sphalerite	17.2%	18.0%	17.7%	17.9%	—
Galena	44.3%	43.3%	41.5%	43.2%	—
Pyrite	—	54.0%	54.5%	54.5%	—
Silver	95.0%	95.0%	92.5%	95.0%	93.0%

A Orcel, J., using the indirect method of Drude, and calculating reflectance from calculated indices of refraction and absorption (4).
B Schneiderhohn and Ramdohr, using the direct photometric method (5).
C Moses, J. H., using the photoelectric method and assigning a value of 54.5 per cent reflectivity to pyrite, used as a comparison standard (1).
D Folinsbee, R. E., using the method of Moses.
E Hagen and Rubens, using a direct method (6).

check with values for other minerals as advanced by various investigators (Table 2), and with calculated values (Fig. 1). In summary, all values reported in this paper are expressed in terms of percentage reflection, and were derived by comparison with a pyrite standard assumed to reflect 54.5 percent of the incident light.

RESULTS.

The results of the investigation are presented in the form of two tables, designed to aid in the rapid identification of ore minerals in polished section. Table 3 presents reflectivity values for nearly all opaque mineral species, listed in alphabetical order, with their formula as given in Dana's System (7), and their behavior in polarized light, appended. The writer's reflectivity values and those of Moses are included in the table, and comparing these, a best value was obtained.

The best values of Table 3 are used as the basis for Table 4, which lists the mineral species in order of increasing percentage reflection. This table can be used to bracket an unknown into a small group of minerals with approximately the same reflecting power.

SUMMARY AND CONCLUSIONS.

Reflectivity of an ore mineral is a fundamental optical constant with a determinative value analogous to that of intermediate index in the nonopaque mineral group. Table 3 can be used to supplement the excellent determinative tables of Short (8). Table 4, patterned after the intermediate index table of Larsen and Berman (9), is valuable in itself for, once an unknown is limited to a small group, association will often suggest its identity. The reflectivity test is easy to make and does not result in destruction of the area tested; it requires little special equipment and no marked mechanical skill.

TABLE 3.

REFLECTIVITY OF THE OPAQUE MINERALS.

Mineral	Formula	Reflectivity and polish[1]			Anisotropism[2]
		Moses	Folinsbee	Best value	
Aguilarite	Ag_4SeS	30.4% P	29.4% P	29.9%	I, W, or S
Aikinite	$PbCuBiS_2$	41.4 F	45.8 G	45.8	D
Alabandite	MnS	23.4 G	22.5 G	23.9	I
Algodonite	Cu_6As	63.2 F	63.6 G	63.6	W
Altaite	PbTe	63.2 F	52.4 P	63.2	I
Andorite	$PbAgSb_2S_4$	36.0 F	36.0 F	36.0	W
Antimony	Sb	69.4 F	74.4 G	74.4	W
Aramayoite	$Ag(Sb, Bi)S_2$	36.7 F	36.7 F	36.7	S
Argentite	Ag_2S	27.3 P	31.6 F(etch)	31.6	W
Argyrodite	Ag_8GeS_6	—	26.6 G	26.6	I or W
Arsenic	As	52.8 P	52.3 P	52.6	D
Arsenopyrite	FeAsS	52.8 F	51.9 G	52.4	S
Awaruite	Fe, Ni	58.0 G	56.5 F	58.0	I
Benjaminite	$Pb(Cu, Ag)Bi_2S_4$	43.6 G	—	43.6	S
Berthierite	$FeSb_2S_4$	34.0 F	34.5 F	34.3	S
Berthonite	$Pb_2Cu_7Sb_6S_{12}$	34.0 F	—	34.0	D
Bismuth	Bi	65.2 P	71.3 G	71.3	D
Bismuthinite	Bi_2S_3	41.0 F	41.0 G	41.0	S
Bornite	Cu_5FeS_4	23.8 G	21.8 G	22.8	I or W
Boulangerite	$Pb_5Sb_4S_{11}$	39.5 F	39.2 F	39.4	D
Bournonite	$PbCuSbS_3$	34.5 F	35.5 G	35.5	W
Braunite	$(Mn, Si)_2O_3$	20.3 F	19.8 F	20.1	W
Breithauptite	NiSb	47.7 F	—	47.7	S
Calaverite	$AuTe_2$	61.1 F	63.2 G	63.2	D
Canfieldite	Ag_8SnS_6	24.0 F	26.6 G(etch)	26.6	I or W
Carrollite	Co_2CuS_4	44.9 G	42.6 F	44.9	I
Cassiterite	SnO_2	12.9 FG	12.0 F	12.9	
Chalcocite	Cu_2S	31.8 F	32.3 G(white)	32.3	W
		—	23.5 G(blue)	23.5	W
Chalcophanite	$(Zn, Mn, Fe)Mn_3O_7 \cdot 2H_2O$	19.1 F	18.5 F	18.8	S
Chalcopyrite	$CuFeS_2$	42.7 F	43.2 G	43.2	W
Chalcostibite	$CuSbS_2$	39.5 F	38.8 F	39.2	D
Chloanthite	$(Ni, Co)As_{3-x}$	56.2 FG	54.1 F	56.2	I
Chromite	$FeCr_2O_4$	12.2 F	12.0 G	12.1	I
		15.7 F	16.4 F	16.1	I
Cinnabar	HgS	26.3 P	—	26.3	
Clausthalite	PbSe	—	50.4 FP	50.4	I
Cobaltite	(Co, Fe)AsS	52.8 FG	52.1 G	52.5	I
Coloradoite	HgTe	34.4 P	37.7 F	37.7	I
Columbite	$(Fe, Mn)(Cb, Ta)_2O_6$	—	18.5 G	18.5	W
Copper	Cu	67.8 FG	72.8 G	72.8	I
	CuAg	70.6 G	78.3 G	78.3	I
Corynite	Ni(Sb, As)S	47.7 F	—	47.7	I or W
Cosalite	$Pb_2Bi_2S_5$	40.1 P	43.0 G	43.0	W
Covellite	CuS	15.5 G	14.6 G(light)	15.1	S
		10.0 FG	8.7 G(dark)	9.5	S
Cubanite	$CuFe_2S_3$	41.6 G	41.0 G	41.3	S
Cuprite	Cu_2O	27.2 P	27.7 G	27.7	D
Cylindrite	$Pb_3Sn_4Sb_2S_{14}$	32.3 F	33.6 F	33.0	D
Delafossite	$CuFeO_2$	22.3 F	22.1 G	22.2	S

[1] Polish is reported on an arbitrary basis as good (G), fair (F), or poor (P).
[2] Anisotropism as reported in Short (8); I—isotropic, W—weak, D—distinct, S—strong.

TABLE 3—*Continued.*

Mineral	Formula	Reflectivity and polish[1]					Anisotropism[2]
		Moses		Folinsbee		Best value	
Domeykite	Cu_3As	52.6	F	50.6	F	51.6	I
Dufrenoysite	$Pb_2As_2S_5$	44.3	P	45.8	FG	45.8	S
Emplectite	$CuBiS_2$	40.4	F	37.7	F	39.1	S
Enargite	Cu_3AsS_4	28.0	G	27.5	F	28.0	S
Eucairite	CuAgSe	47.3	FG	49.9	F	49.9	S
Famatinite	Cu_3SbS_4	26.2	F	—		26.2	S
Ferberite	$FeWO_4$	17.9	G	16.8	F	17.9	D
Franckeite	$Pb_5Sn_3Sb_2S_{14}$	34.9	G	33.1	F	34.9	W
Franklinite	$ZnFe_2O_4$	18.7	G	19.0	G	18.9	I
Freibergite	$(Cu, Fe, Ag)_{12}Sb_4S_{13}$	30.9	F	—		30.9	I
Freislebenite	$Pb_3Ag_2Sb_2S_{12}$	35.7	G	36.0	G	35.9	S
Galena	PbS	41.6	FG	43.2	G	42.4	I
Galenobismutite	$PbBi_2S_4$	26.8	G	—		26.8	S
Geocronite	$Pb_5(Sb, As)_2S_8$	40.7	G	41.0	G	40.9	D
Germanite	(Cu, Ge)(S, As)	23.1	G	—		23.1	I
Gersdorffite	NiAsS	53.7	G	52.3	G	53.0	I
Glaucodot	(Co, Fe)AsS	—		50.0	G	50.0	W
Goethite	$HFeO_2$	16.1	F	15.9	FP	16.1	S
Gold (fine)	Au	64.8	F	73.4	FG	73.4	I
Gaunajuatite	Bi_2Se_3	46.2	F	41.4	P	46.2	S
Guitermanite	$Pb_{10}As_6S_{19}$	—		30.5	P	30.5	D
Hauerite	MnS_2	24.0	F	23.5	F	23.8	I
Hausmannite	$MnMn_2O_4$	19.6	G	18.2	F	19.6	D
Hematite	Fe_2O_3	27.4	FG	27.0	G	27.2	W
Hessite	Ag_2Te	39.3	FG	39.9	G	39.6	I to D
Horsfordite	Cu_5Sb	—		18.0	FG	18.0	
Huebnerite	$MnWO_4$	17.7	G	16.4	G	17.1	S
Hollandite	$MnBaMn_6O_{14}$	—		27.3	F	27.3	S
Ilmenite	$FeTiO_3$	19.2	G	19.6	G	19.4	D
Jamesonite	$Pb_4FeSb_6S_{14}$	37.7	G	37.1	F	37.7	S
Jordanite	$Pb_{14}As_6S_{24}$	38.4	FG	38.4	G	38.4	D
Kallilite	Ni(Sb, Bi)S	47.4	G	46.7	FG	47.4	I
Kermesite	Sb_2S_2O	26.6	F	24.2	P	26.6	S
Krennerite	$AuTe_2$	58.9	FG	62.8	FG	60.9	S
Lengenbachite	$Pb_6(Ag, Cu)_2As_4S_{13}$	36.7	G	—		36.7	W
"Limonite"	$FeO(OH) \cdot n\ H_2O$	17.2	G	17.4	G	17.3	I
Linnaeite	Co_3S_4	47.8	G	46.9	G	47.4	I
Livingstonite	$HgSb_4S_7$	—		31.6	F	31.6	S
Loellingite	$FeAs_2$	53.2	G	53.4	G	53.8	S
Lorandite	$TlAsS_2$	23.8	P	—		23.8	S
Luzonite	Cu_3AsS_4	26.8	F	—		26.8	S
Magnetite	$FeFe_2O_4$	20.7	G	21.4	G	21.1	I
Manganite	MnO(OH)	19.0	F	15.7	P(gray)	19.0	S
		31.4	F	25.9	P(white)	31.4	
Marcasite	FeS_2	50.3	G	52.7	G	51.5	S
Meneghinite	$Pb_{13}Sb_7S_{23}$	37.7	F	34.9	P	37.7	S
Metacinnabar	HgS	27.1	F	26.4	FG	26.8	I to W
Miargyrite	$AgSbS_2$	33.8	G	34.1	G	34.0	S
Millerite	NiS	52.7	FP	54.5	FG	54.5	S
Molybdenite	MoS_2	24.0	F	23.3	P	24.0	S
Nagyagite	$Pb_3Au(Te, Sb)_4S_{5-8}$	39.3	FG	39.0	G	39.2	D
Niccolite	NiAs	51.6	G	53.6	G	52.6	S
Orpiment	As_2S_3	22.0	FG	21.8	G	21.9	W
Pearcite	$Ag_{16}As_2S_{11}$	31.6	F	28.8	F(etch)	30.2	D
Penroseite	$(Ni, Cu, Pb)Se_2$	45.2	FG	30.3	P	45.2	I
Pentlandite	$(Fe, Ni)_9S_8$	45.6	G	42.3	P	45.6	I
Plagionite	$Pb_5Sb_8S_{17}$	37.1	F	37.1	G	37.1	D

TABLE 3—*Continued.*

Mineral	Formula	Reflectivity and polish[1]					Anisotropism[2]
		Moses		Folinsbee		Best value	
Polianite	MnO_2	39.7	F	37.9	FP	39.7	D
Polybasite	$(Ag, Cu)_{16}Sb_2S_{11}$	30.8	F	34.9	G	34.9	D
Polydymite	Ni_3S_4	—		50.4	G	50.4	I
Proustite	Ag_3AsS_3	30.3	FP	29.4	F	29.9	S
Psilomelane	$BaMnMn_8O_{16}(OH)_4$	28.3	G	—	(gray)	28.3	I to D
		32.7	P	—	(white)	32.7	
Pyrargyrite	Ag_3SbS_3	30.7	FG	31.0	G	30.9	S
Pyrite	FeS_2	54.5	G	54.5	G	54.5	I
Pyrolusite	MnO_2	33.1	F	—		33.1	D
Pyrrhotite	$Fe_{1-x}S$	40.2	G	39.5	G	39.9	S
Quartz	SiO_2	—		7.2	G	7.2	W
Rammelsbergite	$NiAs_2$	60.0	G	55.6	P	60.0	D
Rathite	$Pb_{12}As_{16}S_{40}$	34.2	FG	33.1	F	34.2	S
Realgar	AsS	18.7	P	—		18.7	I
Rezbanyite	$Pb_3Cu_2Bi_{10}S_{19}$	43.2	G	43.4	G	43.3	S
Rutile	TiO_2	22.9	G	21.8	F	22.9	S
Sartorite	$PbAs_2S_4$	34.7	G	34.3	FG	34.5	W
Semseyite	$Pb_9Sb_8S_{21}$	37.7	F	—		37.7	S
Scheelite	$CaWO_4$	—		12.0	FG	12.0	W
Silver	Ag	92.5	G	95.0	F	93.8	I
Skutterudite	$(Co, Ni)As_3$	55.4	FG	55.4	G	55.4	I
Smaltite	$(Co, Ni)As_{3-x}$	55.4	F	53.8	G	54.6	G
Specularite	Fe_2O_3	27.4	F	27.1	G	27.3	W
Sperrylite	$PtAs_2$	53.9	G	54.5	G	54.2	I
Sphalerite	ZnS	17.7	G	17.9	G	17.8	I
Stannite	Cu_2FeSnS_4	27.9	F	27.2	F	27.6	W
Steinmannite	PbS	41.6	G	41.4	G	41.5	I
Stephanite	Ag_5SbS_4	29.9	F	29.4	G	29.7	S
Stibnite	Sb_2S_3	38.8	S	39.0	G	38.9	S
Stromeyerite	CuAgS	32.3	P	—		32.3	S
Sulvanite	Cu_3VS_4	29.7	F	28.1	P	29.7	I to W
Sylvanite	$(Ag, Au)Te_2$	55.8	G	56.7	FG	56.3	S
Teallite	$PbSnS_2$	34.5	G	—		34.5	D
Tellurium	Te	56.5	FG	56.5	F	56.5	S
Tennantite	$(Cu, Fe)_{12}As_4S_{12}$	29.0	G	28.6	G	28.8	I
Tenorite	CuO	21.1	FG	20.9	FG	21.1	S
Tetradymite	Bi_2Te_2S	56.9	F	49.1	P	56.9	W
Tetrahedrite	$(Cu, Fe)_{12}Sb_4S_{12}$	31.2	G	29.9	F	31.2	I
Tiemannite	HgSe	25.5	FG	24.0	FG	25.5	I
Troilite	FeS	37.5	FG	30.5	P	37.5	S
Turgite	$Fe_2O_3 \cdot n\ H_2O$	16.4	G	16.7	G(dark)	16.6	W
		19.0	G	18.3	G(light)	18.7	
Ullmanite	NiSbS	47.3	G	48.0	G	47.7	I to W
Umangite	Cu_3Se_2	15.3	F	—		15.3	S
Uraninite	UO_2	15.9	G	16.1	G	16.0	I
Violarite	Ni_2FeS_4	42.1	G	—		42.1	I
Weissite	Cu_9Te_5	31.8		—		31.8	W
Willyamite	(Ni, Co)SbS	47.3	G	45.8	G	46.3	I to W
Wittichenite	Cu_3BiS_3	39.2	G	—		39.2	W
Wolframite	$(Fe, Mn)WO_4$	18.1	G	18.1	G	18.1	D
Wulfenite	$PbMoO_4$	—		19.4	G	19.4	D
Wurtzite	ZnS	17.4	G	17.4	G	17.4	I

TABLE 4.

MINERALS IN ORDER OF INCREASING REFLECTIVITY.

%	Mineral		%	Mineral	
7.2	Quartz	G	29.9	Proustite	FP
9.5	Covellite (dark)	G	30.2	Pearcite	F
12.0	Scheelite	FG	30.5	Guitermanite	P
12.1	Chromite (dark)	FG	30.9	Freibergite	F
12.9	Cassiterite	FG	30.9	Pyrargyrite	G
15.1	Covellite (light)	G	31.2	Tetrahedrite	G
15.3	Umangite	F	31.4	Manganite (white)	F
16.0	Uraninite	G	31.6	Argentite	F(etch)
16.1	Chromite (light)	F	31.6	Livingstonite	F
16.1	Goethite	F	31.8	Weissite	—
17.1	Huebnerite	G	32.3	Chalcocite (argentian)	G
17.3	Limonite	G	32.3	Stromeyerite	P
17.4	Wurtzite	G	32.7	Psilomelane (white)	P
17.8	Sphalerite	G	33.0	Cylindrite	F
17.9	Ferberite	G	33.1	Pyrolusite	F
18.0	Horsfordite	FG	34.0	Berthonite	G
18.1	Wolframite	G	34.0	Miargyrite	G
18.5	Columbite	G	34.2	Rathite	G
18.7	Realgar	P	34.3	Berthierite	F
18.7	Turgite (light)	G	34.5	Sartorite	G
18.8	Chalcophanite	F	34.5	Teallite	G
18.9	Franklinite	G	34.9	Franckeite	G
19.0	Manganite (gray)	F	34.9	Polybasite	G
19.4	Ilmenite	G	35.5	Bournonite	G
19.4	Wulfenite	G	35.9	Freislebenite	G
19.6	Hausmannite	G	36.0	Andorite	F
20.1	Braunite	F	36.7	Aramayoite	F
21.1	Magnetite	G	36.7	Lengenbachite	G
21.1	Tenorite	G	37.1	Plagionite	G
21.9	Orpiment	G	37.5	Troilite	G
22.2	Delafossite	G	37.7	Coloradoite	F
22.8	Bornite	G	37.7	Jamesonite	F
22.9	Rutile	G	37.7	Semseyite	F
23.1	Germanite	G	38.4	Jordanite	G
23.5	Chalcocite (blue)	G	38.9	Stibnite	G
23.8	Hauerite	F	39.1	Emplectite	F
23.8	Lorandite	P	39.2	Chalcostibite	F
23.9	Alabandite	G	39.2	Nagyagite	G
24.0	Molybdenite	F	39.2	Wittichenite	G
25.5	Tiemannite	G	39.4	Boulangerite	F
26.2	Famatinite	F	39.6	Hessite	G
26.3	Cinnabar	P	39.7	Polianite	F
26.6	Argyrodite	G	39.9	Pyrrhotite	G
26.6	Canfieldite	G	40.9	Geocronite	G
26.6	Kermesite	F	41.0	Bismuthinite	FG
26.8	Galenobismutite	G	41.3	Cubanite	G
26.8	Luzonite	F	41.5	Steinmannite	G
26.8	Metacinnabar	F	42.1	Violarite	G
27.3	Specularite	G	42.4	Galena	G
27.3	Hollandite	F	43.0	Cosalite	G
27.6	Stannite	F	43.2	Chalcopyrite	G
27.7	Cuprite	G	43.3	Rezbanyite	G
28.0	Enargite	G	43.6	Benjaminite	G
28.3	Psilomelane (gray)	G	44.9	Carrolite	G
28.8	Tennantite	G	45.2	Penroscite	G
29.7	Stephanite	FG	45.6	Pentlandite	G
29.7	Sulvanite	F	45.8	Aikinite	G
29.9	Aguilarite	P	45.8	Dufrenoysite	F

TABLE 4—*Continued.*

%	Mineral		%	Mineral	
46.2	Guanajuatite	F	54.5	Pyrite	G
46.3	Willyamite	G	54.6	Smaltite	G
47.4	Kallilite	G	55.4	Skutterudite	G
47.4	Linnaeite	G	56.2	Chloanthite	FG
47.7	Breithauptite	F	56.3	Sylvanite	G
47.7	Corynite	F	56.5	Tellurium	FG
47.7	Ullmanite	G	56.9	Tetradymite	F
49.9	Eucairite	F	58.0	Awaruite	G
50.0	Glaucodot	G	60.0	Rammelsbergite	G
50.4	Clausthalite	P	60.9	Krennerite	FG
51.5	Marcasite	G	63.2	Altaite	F
51.6	Domeykite	F	63.2	Calaverite	G
52.4	Arsenopyrite	FG	63.6	Algodonite	G
52.5	Cobaltite	G	71.3	Bismuth	G
52.6	Arsenic	P	72.8	Copper	G
52.6	Niccolite	G	73.4	Gold	F
53.0	Gersdorffite	G	74.4	Antimony	G
53.8	Loellingite	G	78.3	Argentian copper	G
54.2	Sperrylite	G	93.8	Silver	F
54.5	Millerite	F			

The limitations of the method are related to limitations in perfection of polish, and to the fact that an area of about one square millimeter of unknown must be available for the reflectivity test.

DEPARTMENT OF GEOLOGY,
UNIVERSITY OF ALBERTA,
EDMONTON, ALBERTA, CANADA,
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DEPOSITION AND RESOLUTION OF NATIVE SILVER AT GOWGANDA, ONTARIO.

EDSON S. BASTIN.

ABSTRACT.

Reopening of the Miller Lake-O'Brien mine in the Gowganda District, Ontario by the Siscoe Gold Mines, Ltd. offered opportunity to collect samples representative of the richer silver ores and to submit them to paragenetic studies. Special interest centers upon (1) the small number of *abundant* minerals in the ores, (2) the deposition of much native silver with calcite along fractures, (3) direct replacement of fairly fresh as well as highly altered diabase by native silver, (4) the abundance of silver dendrites as automorphic replacements of calcitized diabase, (5) widespread replacement of silver dendrites late in the primary mineralization by calcite, (6) a scarcity of sulphur-bearing minerals in the ores, suggesting that a paucity of sulphur in the mineralizing solutions forced the silver to deposit almost entirely in the native state, (7) absence of evidence that the arsenides functioned as silver precipitants, (8) lack of evidences of colloidal deposition.

INTRODUCTION.

THE writer visited the Gowganda District briefly in 1933 and 1934 to study certain features of its geology [1] but was at that time unable to visit its principal operating mine, the Miller Lake-O'Brien. After being closed down for several years, this property was bought by Siscoe Gold Mines, Ltd., in 1945. Through the courtesy of R. G. Walsh, General Manager, and Dr. W. F. James, Chief Geologist of that Company, the writer paid a brief visit to the mine in July 1948 for the principal purpose of obtaining representative specimens of the richer silver ores. He is indebted to Cornell University for facilities for microscopic studies of these ores. Though restricted in their scope, these studies appear to throw some interesting side lights upon the origin of a type of ore whose genesis has been particularly difficult to interpret.

All of the ore specimens studied were obtained from workings reached through the Main or westernmost O'Brien shaft. Some were collected from the 850 and 1,150 foot levels of No. 11 winze. Others were collected from the high grade ore dump near the collar of the shaft. All these specimens occurred in Nipissing diabase either fairly fresh or hydrothermally altered; indeed 96 percent of all the silver ore from the Gowganda District has, according to Angus Campbell,[2] come from the Nipissing diabase. A small amount has been mined from the Cobalt Series and from the Keewatin immediately above the diabase. The estimated thickness of the Nipissing diabase at the

[1] Bastin, Edson S., "Aplites" of hydrothermal origin associated with the Canadian cobalt-silver ores: ECON. GEOL., vol. 30, pp. 715–734, 1935.

[2] Campbell, Angus, Gowganda silver area: Canadian Inst. Min. Metallurgy Trans., vol. 33, pp. 272–291 and 453–470, 1930.

Miller Lake-O'Brien mine is 1,000 to 1,100 feet. For the general geologic relations at the O'Brien and the adjoining Castle-Trethewey mine the reader is referred to Campbell's paper.

According to Campbell at least 99 percent of the silver is in the native form; a little is present as argentite and still less as ruby silver. Much of the silver is associated with arsenides, mainly of cobalt but subordinately of nickel. According to Campbell, cars of well-cleaned jig concentrates from the Castle-Trethewey mine maintained a very steady average of silver 11.6 percent, cobalt 7.19 percent, and nickel 2.33 percent. Quantitative estimates of the mineral composition of the ore from certain portions of the Miller Lake-O'Brien mine have been made by Thomson [3] on 24 specimens from stopes between the 460 and 730 foot levels.

APPROXIMATE PERCENTAGES OF MINERALS IN ORES FROM MILLER LAKE-O'BRIEN MINE, GOWGANDA, CANADA.

Silver	14½%	Cobaltite	each 1%
Lollingite	13½	Galena	
Skutterudite	9½	Niccolite	
Safflorite	7	Breithauptite	each ½%
Rammelsbergite	4	Chalcopyrite	
Tetrahedrite	3½	Sphalerite	
Smaltite	3		
Chloanthite	2½	Calcite gangue, quartz very subordinate.	
Arsenopyrite	1½		

Additional minerals known to occur in the adjoining Miller Lake-O'Brien and Castle-Trethewey mines are: pyrite, bismuth, stephanite, argentite, and ruby silver. Although these lists include a considerable number of minerals only a few are abundant. To one familiar with the occurrences of this ore type at Cobalt and at South Lorraine the mineralogical simplicity of the Gowganda ores at any one locality is surprising. In the specimens described in this paper essentially the only minerals aside from those of the diabase and its alteration products are calcite, native silver, argentite and lollingite.

SILVER VEINS IN THE NIPISSING DIABASE.

A common mode of silver occurrence is in veins following fractures in the diabase. Rarely silver occurs alone in such fractures and conversely many calcite veins seem to carry no silver. Dominantly, however the native silver is accompanied by abundant white calcite, the two minerals being irregularly intercrystallized. The silver of the veinlets rarely if ever shows automorphic outlines. It seems not to have replaced calcite along fractures or cleavages, rather the two minerals seem to have interfered in their growth and are interpreted as contemporaneous. According to Campbell, the veins vary in width from a fraction of an inch to several inches and in exceptional cases to 3 or 4 feet. Those seen by the writer were all small and carried only thin flakes or sheets of silver.

It is doubtful if any of the Nipissing diabase is entirely unaltered but silver veinlets occur abundantly in some that is surprisingly fresh appearing,

[3] Thomson, J. E., A mineralographic study of the minerals of the Miller Lake-O'Brien Mine, Gowganda, Ontario: Toronto Univ. Studies, Geol. ser. no. 35, pp. 61–64, 1933.

twinning in the plagioclase feldspars being recognizable, cleavage identifiable in the ferro-magnesian silicates and the diabasic texture being conspicuous. While most of the silver is confined to the veinlets, rarely tiny silver grains are scattered through the diabase between the veinlets. Testing with dilute HCl usually reveals the presence of some calcite with this disseminated silver.

The presence of argentite in some of the veinlets raises the question whether the native silver is an alteration product of the argentite. The answer is believed to be no. Alterations of argentite to silver with the development of wires or "teeth" of silver growing out of argentite were not observed nor were there any ragged replacement contacts of silver against argentite, the few contacts observed being smooth and regular. Conversely no evidence was found that the argentite was an alteration product of silver through the agency of H_2S. The argentite, like the silver, is intimately intergrown with calcite and was therefore deposited from alkaline solutions whereas H_2S-bearing solutions would be acid. The three vein minerals-calcite, silver and argentite are interpreted as contemporaneous.

Along many of the mineralized fractures there has been little movement but along others some displacement is indicated by slickensided surfaces coated with what appears to be chlorite. Along some such fractures silver is moulded to the slickensided surfaces.

SILVER ASSOCIATED WITH ARSENIDE PELLETS.

A second mode of occurrence of silver is in association with pellets of arsenides sometimes in fairly fresh appearing Nipissing diabase but more commonly in what is almost certainly altered diabase since in many places

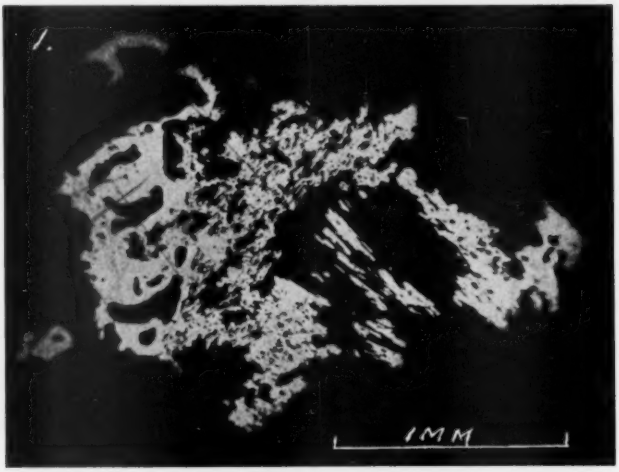


FIG. 1.

it grades into undoubted diabase. The altered rock carries abundant calcite and also carries chlorite in rotund masses of radiating blades. Though usually in much smaller grains, calcite occasionally forms crystals up to 2 cm across. The arsenides form rotund pellets 1 to 2 mm across occurring singly or in small clusters.

Silver is not invariably present in these arsenide-bearing ores but when it does occur most of it is in grains closely associated with the arsenides and in places forming cores enclosed by rims of arsenides. Minor amounts form tiny silver veinlets following fractures. Where, more rarely, silver replaces relatively little altered diabase, polished surfaces show that its pattern varies notably from point to point as shown in Figure 1. A thin section from an adjacent area of the same specimen reveals that the silver is a direct replacement of the diabase minerals and that the different patterns of the silver are due to the replacement of different rock mineral grains, the silver being pseudomorphic after the several rock minerals in contrast to the automorphic replacements next to be described. Among the diabase minerals hornblende was particularly susceptible to such replacement but silver also replaced both the quartz and the microcline of granophyric intergrowths and to a minor extent replaced plagioclase.

SILVER DENDRITES.

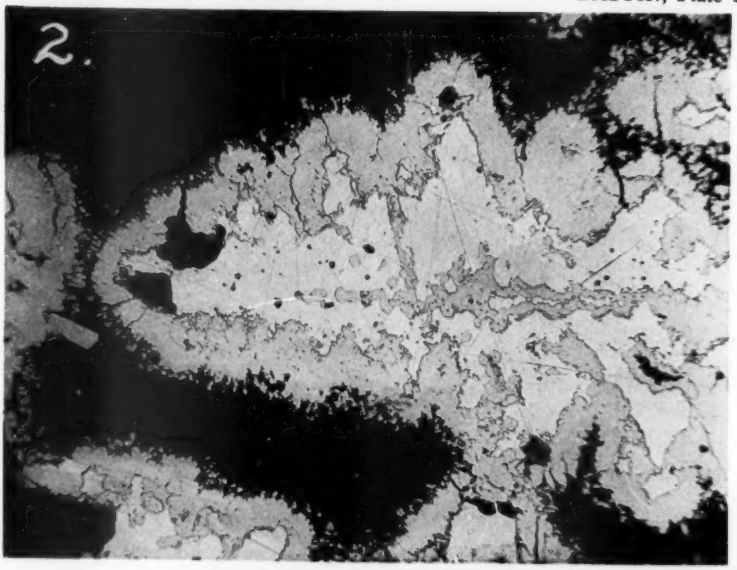
A third mode of occurrence of native silver is in arborescent, dendritic or skeletal forms of silver and arsenides in a matrix almost exclusively calcite. The megascopic appearance has been beautifully illustrated in a recent article by Montgomery,[4] and its appearance under low magnification by Todd.[5] As pointed out by both of these authors, the dendritic pattern of the metallics appears to be controlled by the crystal habit of the native silver which forms the cores of most of the metallic areas. To quote Todd (p. 76):

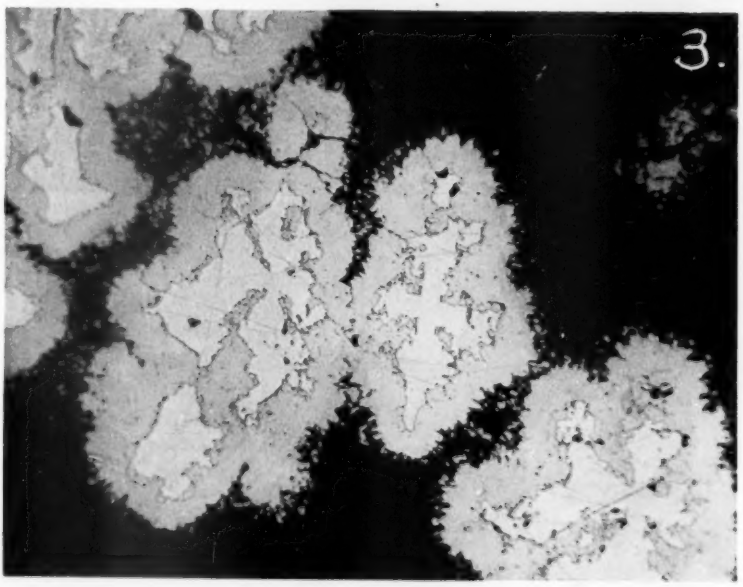
> From a block of this ore, the silicate and carbonate gangue minerals were removed by the use of strong hydrofluoric, sulphuric, and hydrochloric acids, a process which affected the arsenides in an astonishingly small degree. The metallic growths remained firmly bound together in their original positions. This work, done with the object of observing the angles of intersection of the planes of growth in the dendrites, shows that the common angle is 90 degrees, which suggests free growth of a cubic mineral (silver) as the controlling factor in the development of the dendrites.

As seen under the compound microscope, in the large, the outer borders of the arsenide areas are rotund, often compoundly so to form an escalloped border always convex outward (Figs. 2 and 3). Viewed in detail, however, these outer borders are not smooth but rough being made up of very small, automorphic crystals usually elongate nearly at right angles to the outer periphery (Fig. 2). Usually the outer periphery of the arsenide envelope

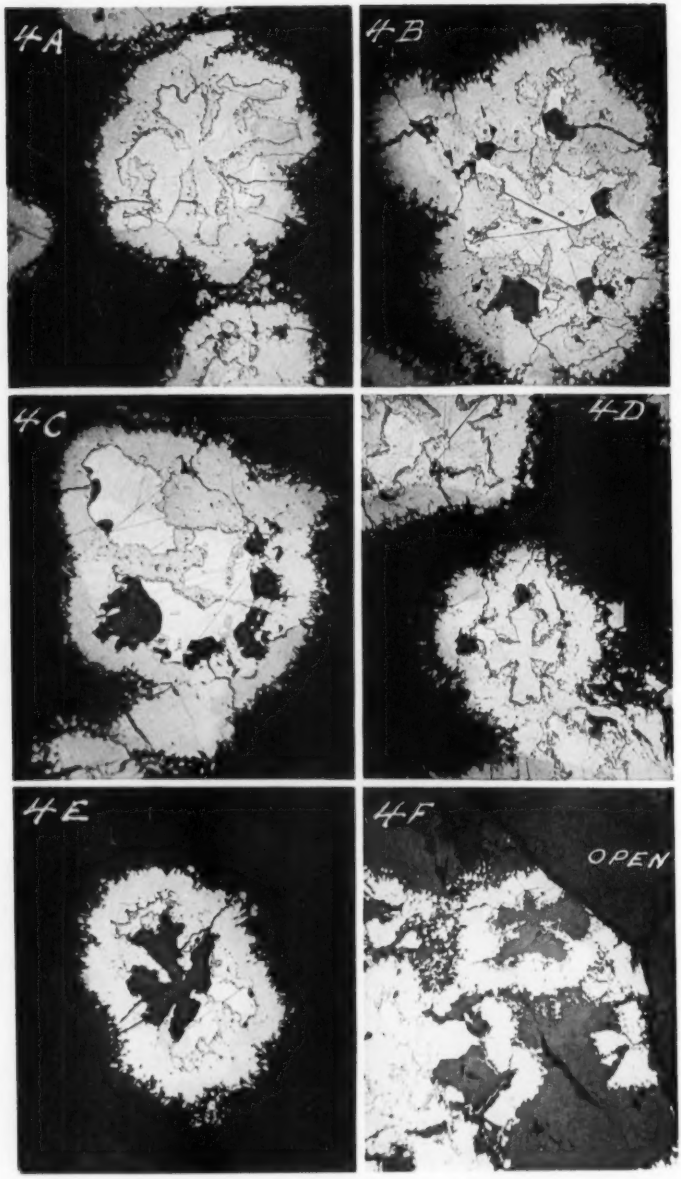
[4] Montgomery, Arthur, Mineralogy of the silver ores of Gowganda, Ontario: Toronto Univ. Studies, Geol. ser. no. 52, pp. 23–38, 1948.

[5] E. W. Todd, Gowganda vein minerals: Ontario Dept. Mines 35th Ann. Rept., Part 1, Fig. 11, p. 74, 1926.





FIGS. 2 and 3



FIGS. 4A-4F

is single but occasionally it is double, a layer of small arsenide crystals being separated by a layer of calcite from the main arsenide mass.

A characteristic view of one of the dendrites as seen under the microscope in *longitudinal* section is shown in Figure 2. This shows the core of silver (white), the envelope of arsenides (gray), and the matrix of calcite (black). It shows the rotund to escalloped general outlines of the contacts between the arsenides and the calcite matrix and it shows also the irregularity of this contact when viewed in detail. It also shows the irregularity in detail of most of the contacts between the arsenides and native silver.

Cross-sections of three dendrites of silver enveloped by arsenides are shown in Figure 3 and of another in Figure 4A. In these it can be seen that the silver commonly shows cruciform outlines within the arsenides, some being four-armed and some five-armed. The cross-sections of other silver cores are less regular (Fig. 5). These figures also show that the silver outlines though cruciform in their larger pattern are very irregular in detail. This minor irregularity is shown by the microscope to be due to intimate intergrowths of silver and arsenides along their contacts.

After the deposition of the silver cores and their enclosing envelope of arsenides there was, in a few places, a further deposition of native silver by the replacement of calcite *outside* the dendrites as is well shown at A in Figure 5. As shown in this figure this late silver conforms to the prismatic outlines of small crystals of the arsenide. Rarely vein-like masses of late silver traverse the arsenide as shown in Figure 7. Along the walls of this veinlet silver and arsenide crystals interlock indicating, it would seem, that fracturing and the deposition of the late silver began before the deposition of arsenides ceased.

Besides such occurrences as shown in Figure 7 there are other evidences of fracturing after the deposition of arsenides. The first is local brecciation illustrated in Figure 8 in which several dendrites can be seen to be fractured, broken into displaced segments, or completely shattered into a multitude of small angular fragments. The calcite matrix is dark gray and the arsenides light gray. The roughly vein-like areas of native silver (Ag) show no fracturing or brecciation either because they are younger than the fracturing or because they yielded to deformation by flowage rather than by fracturing. The latter interpretation is favored.

Where the deformation was less severe it produced only narrow fractures traversing the arsenide envelopes but apparently not entering the silver. In these fractures calcite was deposited in continuity with that of the matrix and in Figures 4A to 4E they are visible as narrow black veinlets.

Dendrites or arborescent forms are a common feature of ores of the Cobalt-Nickel-Silver type in districts widely scattered over the World. As the writer has pointed out,[6] most though not all of these are enveloped in arsenides which in turn are surrounded by a matrix usually of calcite. In most cases the cores of the dendrites are native silver and their forms are those of an isometric mineral. Dendrites of bismuth are sometimes present in the

[6] Bastin, Edson S., The interpretation of ore textures: Geol. Soc. America, in press.

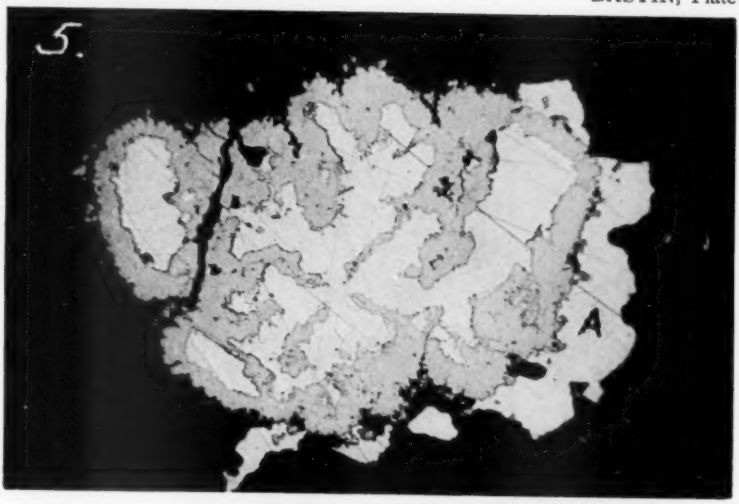
same ores but their forms are different from the silver dendrites. Of especial interest is the fact that in many of these ores certain of the dendrites, though retaining the forms characteristic of silver dendrites, are now composed partly or wholly of other minerals. Among these other minerals calcite is of commonest occurrence but others include proustite, argentite, galena, sphalerite and chalcopyrite. The resulting textures have been variously interpreted, usually avoiding the simplest explanation that all these minerals were replacements of native silver that constituted the original cores and remnants of which remained.

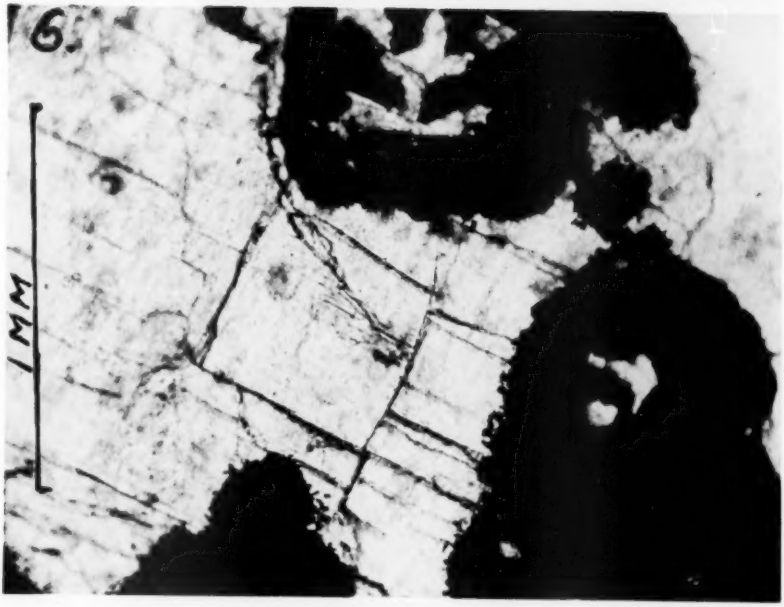
The Gowganda ores are of particular interest because they seem to offer conclusive evidence of replacement of original silver cores of dendrites by calcite and in Figure 4 is shown in a series of cross-sections a progressive series from cores almost wholly silver to cores wholly calcite. In A a five-armed cross of silver lies within an envelope of arsenides and represents a dendrite almost in its original condition except that the arsenide envelope has been fractured in a few places and tiny veinlets of calcite (black) occupy the fractures. These begin at the calcite matrix and end at the silver core without penetrating it. Where some of these veinlets reach the silver they show slight bulbous enlargements representing the beginnings of silver replacement by calcite. In B an irregular core of silver occurs within an envelope of arsenides which is traversed by several calcite veinlets (black). These begin at the calcite matrix, preserve a vein-like form in the arsenides but when they encounter the silver of the core they enlarge abruptly to roughly bulbous calcite areas which, however, usually show crystalline outlines next the silver. In other words, calcite-bearing solutions penetrating along fractures in the arsenides have accomplished the automorphic replacement of silver by calcite. In C it is clearly the outer portions of the silver core that have first been replaced by the calcite. Some but not all of the feeder veinlets of calcite traversing the arsenides are shown. In D the tips of two arms of a four-armed cross have been replaced by calcite. In E over half of the silver core has been replaced by calcite, the parts that were replaced being those nearest the fractures traversing the arsenides. Finally in F all of the silver has been replaced by calcite but the crusiform outlines have been preserved. In a longitudinal section of a dendrite replacement of portions of the silver core by calcite is well shown in Figure 2. The feeding veinlets of calcite traversing the arsenides are shown.

COMPOSITION OF THE ARSENIDES.

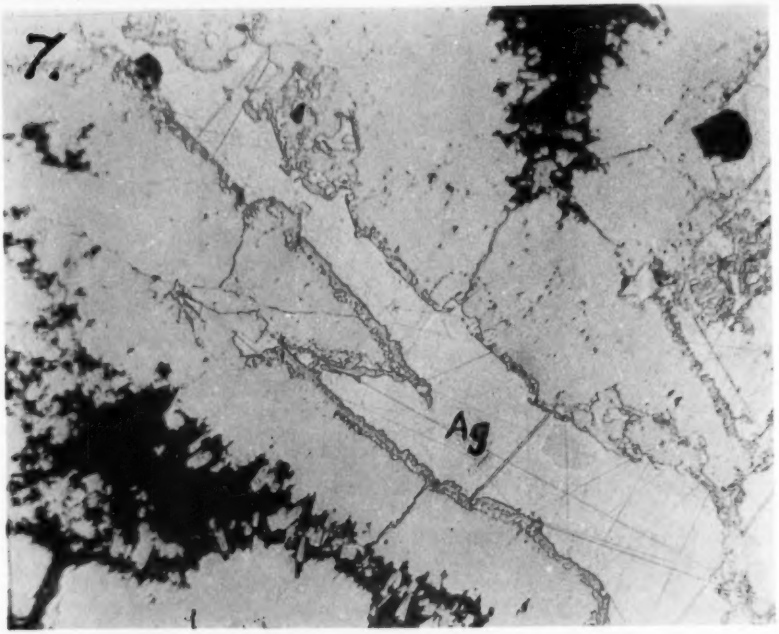
The studies of Thomson and others have shown that while there is a considerable number of minerals present in the ores of the Miller Lake-O'Brien mine, only a few of these are abundant. The three most abundant arsenides are lollingite, skutterudite and safflorite.

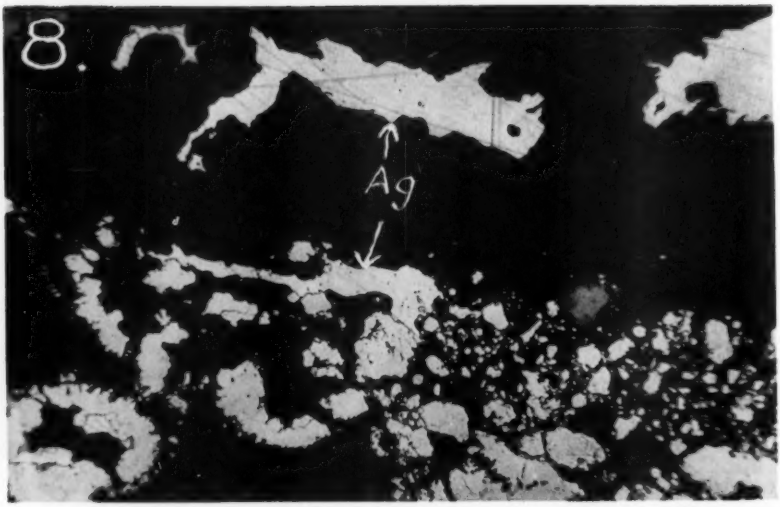
In the specimens collected and studied by the present writer and described in this paper the only arsenide present in the ores answers all the tests for lollingite listed in Short's "Microscopic Determination of the Ore Minerals," being negative to all the standard etch reagents except HNO_3. It is orthorhombic and its polarization colors are light yellow to deep blue. It seems





FIGS. 5 and 6





FIGS. 7 and 8

likely that in these fine-grained ores there are considerable variations in the proportions of cobalt and iron in the arsenides due in part to variations in the proportions of lollingite present and also to variability within the general formula $(CoFe)As_2$.

SUMMARY OF MINERAL PARAGENESIS.

The sequence of events revealed by the study of these Gowganda ores is illustrated diagrammatically in Figure 9. Local fracturing of the Nipissing diabase and its extensive replacement by calcite constituted the prelude to the deposition of silver and the other metallic minerals.

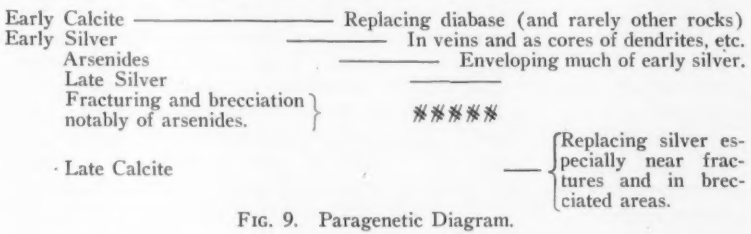

Early Calcite
Replacing diabase (and rarely other rocks)
Early Silver
In veins and as cores of dendrites, etc.
Arsenides
Enveloping much of early silver.
Late Silver
Fracturing and brecciation notably of arsenides.
Late Calcite
Replacing silver especially near fractures and in brecciated areas.

FIG. 9. Paragenetic Diagram.

Some of the early silver occurring as veins and veinlets was accompanied by white calcite as its principal and usually its sole gangue. Calcite deposition then declined and silver was deposited as tubercles and dendrites by the replacement, largely automorphic, of carbonatized diabase. Where, occasionally, the replacement affected relatively fresh diabase it was in part pseudormorphic, the forms assumed by silver being notably influenced by the minerals of the diabase as shown in Figure 1. In the highly calcitized diabase, on the contrary, the forms assumed by both the early silver and the arsenides are largely independent of the calcite and other minerals of the host as shown in Figure 6. This is from a thin section, and the arsenides, which appear black, can be seen to have developed without regard to the well-displayed cleavage of the early calcite (mottled gray). It may be noted in passing that, near the top center of this figure, late calcite has developed by the replacement of the early silver core of a dendrite with the preservation of the original cruciform outlines.

After the early silver there followed, with a slight overlap, the deposition of arsenides around the silver as automorphic replacements of altered diabase (Figs. 2 and 3). After the arsenides there followed, with slight local overlap, further deposition of native silver. This silver may partially envelop arsenide areas (Fig. 5) or may form irregular vein-like areas in the calcitized diabase (Fig. 8).

The deposition of the arsenides was succeeded by deformation which is evidenced by fracturing and brecciation (Fig. 8) in the relatively brittle arsenides. The associated silver must also have been under stress but appears to have yielded by flowage rather than by fracturing.

Finally, there was a *removal* of silver in solution on a considerable scale as evidenced by its frequent partial or complete replacement by calcite. This

is most clearly shown in the dendrites of early silver (Figs. 4A to 4F) but seems also to have affected late silver, for the calcite in contact with late silver (Fig. 8) usually assumes its own automorphic outlines just as does the calcite that has replaced the early silver. What became of the silver dissolved by carbonate solutions in this episode in the ore history remains uncertain.

All the successive episodes of mineralization that have here been described are interpreted as hypogene (primary). What inferences can we draw as to the chemical nature of the mineralizing solutions and the mechanism of precipitation? First, the abundance of calcite as a gangue, almost to the exclusion of other gangues, indicates that the bicarbonate radicle was probably the dominant acid radicle in the solutions. These were probably alkaline. Thomson's estimates of the relative abundance of the various metallic minerals in the ores are useful in indicating the abundance of arsenic and the paucity of sulphur in the ores and, by inference, in the mineralizing solutions. Only a small fraction of the silver therefore was precipitated as sulpho-salts (ruby silver) and sulphides (argentite). Although some of the silver is slightly antimonial,[7] none has been shown to be arsenical. The bulk of the silver in solution therefore, finding no willing and sufficient chemical partners was forced to precipitate in the native state.

The extreme mineralogical and chemical simplicity of the ores of that area of the mine from which the ores studied were obtained also tends to simplify the problem of silver precipitation. Again the paucity of sulphur is emphasized for the only sulphide in the collection was a small amount of argentite. Probably this paucity of sulphur was the principal cause of the deposition of silver in native form. Although it is known that, in the laboratory, the simple arsenides of iron and cobalt are effective precipitants of native silver from most silver solutions there is no textural evidence that in these ores the iron arsenide—lollingite—functioned in this fashion; replacements of lollingite by native silver which would constitute such evidence are lacking. If arsenic in solution had functioned as a precipitant we might expect the silver to be arsenical which seems not to be the case. Furthermore the direct replacement of both fairly fresh and of altered diabase by native silver both before and after the stage of arsenide deposition again suggests that the arsenides, solid or in solution cannot be held responsible for the silver deposition. It appears logical to attribute the successive episodes of deposition and solution of calcite and of silver displayed in Figure 9 to changes in equilibrium within a mineralizing solution particularly rich in silver and the bicarbonate radicle and particularly poor in sulphur.

All evidences point to the deposition of the ore minerals at Gowganda in the crystalline and not in the colloidal state. Pitchblende, which is a minor colloform associate of the crystalline components of ores of this type in many other districts, has not been found at Gowganda.

ITHACA, N. Y.,
March 19, 1949.

[7] Montgomery, Arthur, op. cit., p. 31.

A DEVICE FOR CALCULATING STOPING VALUES FROM ASSAYS OF NARROW VEINS.[1]

FREDRICK C. KRUGER.

ABSTRACT.

The construction and use of a "slide rule" device is described for easy determination of the value per ton of a narrow vein when the width of the stope exceeds the width of the vein.

INTRODUCTION.

Correction of the assays for each metal of a narrow vein, for dilution by wall rock entailed in breaking to the minimum width of the stope, is easily accomplished on the A and B or C and D scales of an ordinary slide rule. To determine whether or not these combined values (assuming three or fewer metals) will make the cut-off for ore grade, a triangular diagram of the type described by Altshuler [2] can be conveniently used. However, if the actual value in dollars or metal-equivalents is desired, additional simple, though time-consuming, multiplications and addition are necessary. The home-made device described in this paper combines all of these operations and facilitates the computation. It was designed for and used in the geological and mine offices of an operating property.

The "assay slide rule" can be applied to any multi-metal ore and can be expanded by adding one or more slides; the curves for width of vein can easily be changed to any desired minimum stoping width; and if the metal prices change, new scales can be easily calculated and changed. If it is desirable, the stationary, vertical and horizontal scales for dollar-equivalents can be changed so that the values can be obtained in metal-equivalents instead.

DESCRIPTION.

The "assay slide rule" illustrated in the accompanying drawings (Figs. 1A and 1B) is in practice about 20 inches square and about ⅜ inch thick. The baseboard and the sliding pieces may be constructed of either wood or metal and faced with drawing paper for marking the scales and guide lines.

The scale for "% Cu" is pasted directly on the left hand edge of the baseboard and is stationary. The next two scales, to the right, for "Oz. Ag" and "Oz. Au" are pasted on tongued and grooved pieces, about ¼ inch thick, and are fitted into channels so that they can slide independently of each other. Both the vertical and horizontal scales for "Dollars" are pasted onto the baseboard and are stationary.

[1] Published with permission of the Cerro de Pasco Copper Corporation.

[2] Altshuler, H. I., Determining cut-off grades with triangular coordinates: Eng. and Min. Jour., vol. 139, no. 10, pp. 35–38, 1938.

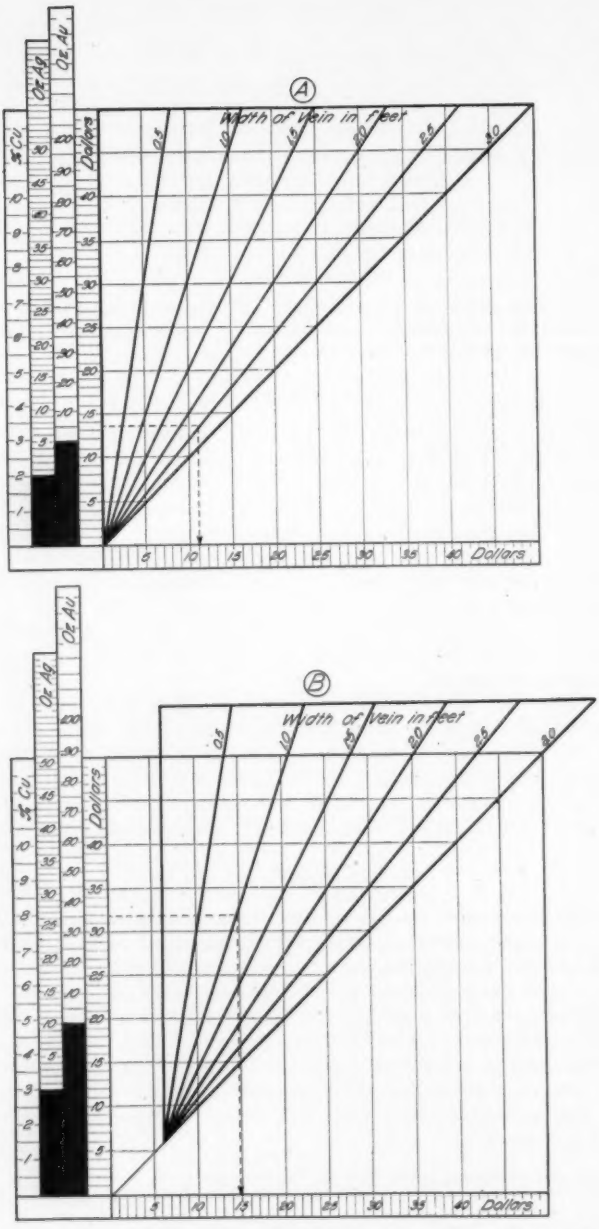


FIG. 1. Illustration of "assay slide rule" discussed in text. (A) Calculation with barren wall rock. (B) Calculation with $6.00 values in wall rock.

The curves for "Width of vein in feet" are plotted on a 45° triangular piece of transparent celluloid, which is set into the baseboard the depth of the thickness of the sheet of celluloid, but is still free to slide along its hypotenuse. The face of the baseboard, beneath the celluloid triangle, is covered with drawing paper on which horizontal and vertical guide lines have been ruled.

CONSTRUCTION OF SCALES AND CURVES.

In practice such economic factors as sampling errors, over-break in stoping, and recoveries of metals in concentrating, smelting, and refining would have to be considered in designing the scales for each metal, but conditions have been idealized for the purpose of this paper and these factors have been omitted. These illustrations are made up for a copper-silver-gold ore and are based on hypothetical metal prices of $0.20 per pound of copper (1% copper = $4.00 per ton), $0.75 per ounce of silver and $35.00 per ounce of gold; or converting into dollar-equivalents: $1.00 = 0.250% copper or 1.333 ounces silver or 0.029 ounce gold. With these data the scales for the assay units of each metal can be laid out according to their dollar-equivalents. The scales should be made to allow for the highest assays anticipated for each metal in any particular stoping operation.

The minimum width for a stoping operation is usually determined only by experience because it will vary according to the attitudes of the vein, the character of the rock in hanging wall and footwall, the nature of the ore, and the skill of the miner. In the accompanying examples, a minimum width for stoping of 3.0 feet has been assumed. This means that if the vein is 3.0 feet wide, or more, its values will not have to be diluted with lower grade wall rock because, under ideal conditions of mining, only the vein will have to be extracted. If the vein is only 1.0 foot wide, the vein can be stoped, but it will be necessary to break an additional 2.0 feet of wall rock, to make working space, so that the overall grade will be only one-third as rich.

In these diagrams the curve for 0.0 width is vertical and that for 3.0 feet width is at 45°. For the intermediate curves, points may be calculated and plotted, or the angles may be worked out from the natural tangent functions. Of course, any adopted stoping width may be ascribed to the 45° line and the intermediate curves plotted accordingly.

MANIPULATION OF THE DEVICE.

The sliding scales are calibrated in dollar-equivalents so that the assays of the various metals can be added to arrive at a value in dollars for the complete assay; and the curves solve the proportion:

$$\frac{\text{value in dollars at width of vein}}{\text{value in dollars at width of stope}} = \frac{\text{width of vein}}{\text{width of stope}}.$$

For example, assume a vein 2.5 feet wide containing 2.0% copper, 5.0 ounces of silver per ton, and 0.05 ounce of gold per ton (Fig. 1A). Opposite 2.0 on the "% Cu" scale place the zero point of the "Oz. Ag" scale. Opposite

5.0 on the "Oz. Ag" scale place the zero point of the "Oz. Au" scale. Opposite 0.05 on the "Oz. Au" scale read $13.50 on the vertical "Dollars" scale. This is the value of the assay of the vein over 2.5 feet of width. To find the value at the minimum stoping width of 3.0 feet follow $13.50 horizontally to the right, to the curve for 2.5 feet, and then follow vertically down to the horizontal "Dollars" scale and read $11.00, which is the indicated value per ton of the mixture of ore and wall rock.

The example above assumes that the 0.5 foot of wall rock contains no values; however, the diagram can also take into account the values in the wall rock. To introduce this variable into the diagram the triangular piece of transparent celluloid is moved along its hypotenuse so that the origin of the curves coincides with the dollar-equivalents of the metals contained in the wall rock.

For example, assume a vein 1.0 foot wide assaying 3.0% copper, 10.0 ounces silver per ton, 0.35 ounce gold per ton, and wall rock assaying 1.0% copper, 2.0 ounces silver per ton, and 0.02 ounce gold per ton (Fig. 1B). The vein over 1.0 foot width has a value of $31.75, and the wall rock contains an additional $6.00, so that the value at 3.0 feet width is $14.75.

In actual practice the scales and curves have more subdivisions than shown here and thus can supply more detailed information, but that is a refinement that can be suited to the individual needs.

CERRO DE PASCO COPPER CORPORATION,
LA OROYA, PERU, SOUTH AMERICA,
March 3, 1949.

DISCUSSION AND COMMUNICATIONS

APPARATUS FOR THE RECORDING OF DECREPITATION IN MINERALS

Sir: In connection with work being done in this department on geothermometry by means of the decrepitation technique a need was found for apparatus to record the decrepitation. The method described by Scott [1] consists essentially of heating a sample of the mineral in a glass tube suspended in an electric furnace and by means of a rubber tube, or microphone-amplifier-headphone link, listening to the decrepitation as it takes place, simultaneously interpreting what is heard in the form of notes. The limitations of this arrangement are numerous, the chief being that of subjective variations. The success of the decrepitation technique at the present time depends mainly on the ability of the observer to decide at what temperature decrepitation commences in the case of minerals devoid of secondary liquid inclusions. Or, if the latter are present, at what temperature the rate of decrepitation increases, since the explosions of the primary inclusions are superimposed on those of the secondary inclusions. In the case of minerals without secondary inclusions it is not very difficult to decide when the first faint explosion has taken place, but nevertheless, it can only be recorded after it has appeared, introducing sometimes considerable error. Also, since there is a statistically smaller chance that explosions will take place as soon as the inclusions are filled by liquid than after that time, the explosions will only begin at the point of filling when an infinitely large number of fragments are heated. A finite number will start exploding a little above the temperature at which the inclusions are filled. However, the change in the rate of explosions after they start, when extrapolated back, should give the temperature when explosions would have just started if more fragments had been heated. When there is the necessity of determining a change in the rate of decrepitation the mental integration method is not reliable, because it takes considerable training to observe such a change and it is virtually impossible to record its occurrence with anything like the precision necessary. Consequently the apparatus and technique described below were developed, enabling a permanent record to be made of each decrepitation run.

As in the technique described by Scott, the sample of the mineral being studied is placed in a pyrex glass tube having a thermocouple built into a

[1] Scott, H. S., The Decrepitation Method Applied to Minerals with Fluid Inclusions: ECON. GEOL., vol. 43, no. 8, pp. 637–654, 1948.

depression in the wall so that the hot junction will lie as close as possible to the mineral sample. The tube is mounted so that the end carrying the mineral may be suspended in a small electric furnace, the temperature of which can be controlled. A demountable crystal microphone of the pressure type is fixed to the other end of the tube, care being taken to insulate it well from the heat of the furnace.

The output from the microphone is amplified by means of a four-stage conventional resistance-capacity coupled vacuum tube amplifier. Arrangement is made at this point to monitor the signal by headphones. The output from the amplifier is applied to an electronic relay of the unbalanced multi-

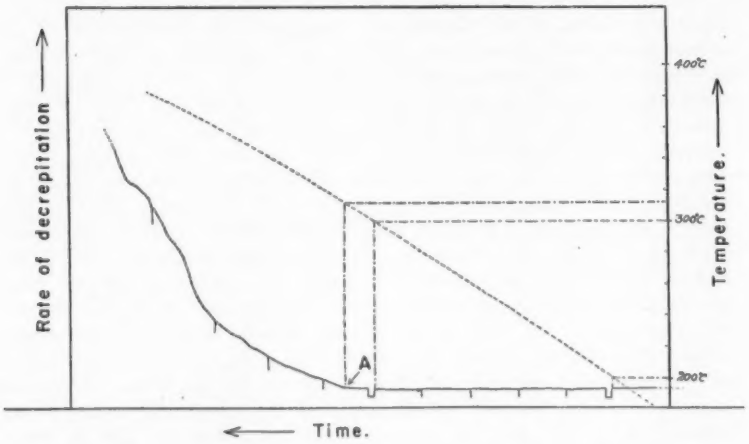


FIG. 1. Decrepitation curve of *amblygonite* from Buck Claims, Bernic Lake, Manitoba, November 22, 1948. The broken curve represents the rate of rise in the temperature. Point A on the decrepitation curve corresponds to 312° C on the temperature curve.

vibrator type, the transients produced by the minute explosions triggering the relay. In this way voltage pulses of random value and duration are converted to pulses of controllable intensity and duration. A conventional resistance-capacity timing-circuit integrates the pulses from the relay. By varying the time constants of the circuit the decay time can be selected, in order to compensate for variation in the frequency of explosions from one mineral to another. The integrating circuit is such that a potential is developed proportional to the frequency of pulses impressed on the circuit. This potential is amplified and used to control a power amplifier tube in the plate circuit of which is coupled an Evershed and Vignoles recording milliameter.

Thus, the sound of explosions picked up by the microphone will produce a deflection on the recorder, the amount of deflection being proportional to the frequency of the explosions. The recorder, since the movement of the paper is controlled by a clockwork mechanism, draws a curve of frequency against time. Therefore provision is made to superimpose on the curve, fiducials representing temperature steps. This allows a temperature-time curve to be drawn, which helps in interpolating between temperature fiducials on the frequency-time curve. This is usually not necessary, since between fiducials the temperature-time curve is substantially linear.

Examination of Figure 1, which is a reproduction of part of a decrepitation record made with the above apparatus, will show that at point A there is a very sharp change in the shape of the curve. This change represents the commencement of decrepitation at 312° C. This temperature we believe to be that at which the liquid in the inclusions just filled the space available.

The apparatus is being modified progressively so that there will be maximum shielding of ambient noise from the microphone, minimum temperature difference between the recording thermocouple and the charge, and maximum amount of the charge contributing to the detected decrepitation.

F. G. SMITH AND P. A. PEACH.

GEOCHEMICAL LABORATORY,
DEPARTMENT OF GEOLOGICAL SCIENCES,
UNIVERSITY OF TORONTO,
TORONTO, CANADA,
December 27, 1948.

HIGHER ALUMINA CONTENT OF OAK LEAVES AND TWIGS GROWING OVER CLAY PITS.

Sir: The ash from a few samples of oak leaves and twigs was spectrographically analyzed qualitatively, with a rough quantitative estimate, and found to be richer in alumina where the trees grew over clay deposits rich in alumina. The few analyses were run incidental to another project and because additional analyses are not now contemplated, this brief note is offered for what interest it may bring to the field of geochemistry.

During the spring of 1947, after the trees were in full leaf, a few grams of leaves and twig ends from post oak [1] and hickory growing over clay pits and nearby barren (of clay) land in Missouri as indicated in the table below were collected. Because the leaves were newly grown, and because a rainy spell preceded shortly the collecting of the specimens, they are believed to be entirely free from contamination by dust. Leaves and young twigs were sampled because fresh growth reflects most closely the effect of inorganic nutrients derived from the soil. The trees were about 6 inches in diameter.

[1] Identification confirmed by Professor R. H. Westveld, Department of Forestry, University of Missouri.

SPECTROGRAPHIC ANALYSES OF TREE ASH.

Sample no.	Elements present												
	Al	Mg	Ca	Na	K	Fe	Mn	Ti	Zn	Cu	Ba	B	Si
1	s	M	m	m	s	s	s	t	t	t	t	s	m
2	s	M	m	m	s	s	s	t	t	t	t	s	m
3	s	M	m	m	s	s	s	t	t	t	t	s	m
4	s	M	m	m	s	s	s	t	t	t	t	s	m
5	s	M	m	m	s	s	s	t	t	t	t	s	m
6	s	M	m	m	s	s	s	t	t	t	t	s	m
7	s	M	m	m	s	s	s	t	t	t	t	t	m
8	s	M	m	m	s	s	s	t	t	t	t	t	m
1L	s	M	m	s	s	s	s	t	t	t	t	s	m
1T	s	M	m	s	s	s	s	t	—	t	t	s	m

Special comment by analyst: "More Al in No. 1 and 2 than in No. 3; slightly more Al in No. 4 than in No. 5; about twice as much Al in No. 7 as in No. 8; more Al in Nos. 4 and 5 than in Nos. 6 and 3; Nos. 1L and 1T about the same."

Symbols:

M	major constituent,	1% or more
m	minor constituent,	approx. 0.1 –1.0%
s	small amount,	approx. 0.01–0.1%
t	traces,	below .01%

No. 1, Small oak tree growing directly on flint fire clay, near Linn, Missouri.

No. 2, Second oak tree on same clay pit as No. 1.

No. 3, Small oak tree about ⅜ mile east of flint clay pit (Nos. 1 and 2), on Pennsylvanian Cherokee shale and sandstone covered by a thin soil mantle.

No. 4, Small oak tree growing over a diaspore pit. Solid diaspore is covered from 1 to 3 feet. East of Mint Hill, Missouri.

No. 5, Small oak tree about ¼ mile from No. 4. Pennsylvanian sandstone underlies the area.

No. 6, Small oak tree over flint clay pit. About 6 feet of soil and overburden covers the clay. West of Mint Hill, Missouri.

No. 7, Small hickory tree over an "irony" (hematite) diaspore pit. Solid diaspore is covered by 3 feet to 6 feet of cherty, gravelly, sandy to clayey residuum which contains some boulders of diaspore clay. Between Linn and Mint Hill, Osage County, Missouri.

No. 8, Small hickory tree about ¼ mile north of No. 7, Pennsylvanian rock under soil.

No. 1L, Leaves only, from tree No. 1.

No. 1T, Twigs only, from tree No. 1.

The leaves and twigs were preserved and partly dried in paper sacks and ashed in an electric muffle at red heat in a platinum dish. The ash samples were excited directly in a carbon arc of a Hilger spectrograph, and estimates [2] of relative compositions were made by comparisons of line densities on the photographic plate.

VARIATION IN ALUMINA CONTENT OF THE TREE ASH.

The table of analytical results is self-explanatory. The analyses obviously are not even semi-quantitative, but they indicate in general what inorganic

[2] Analyses were made by Dr. E. E. Pickett, spectroscopist in charge of the Spectrographic Services, University of Missouri. Expenses of the analytical work were defrayed under University of Missouri Research Council Grant No. 287.

elements the oaks and hickories extract from the soil. The special comments of the analyst, wherein he estimates within the ten-fold range of his symbols, are of greatest interest as regards the alumina content.

However, before examining in detail the variation in alumina content within the samples of tree ash, attention should be called to the variation in alumina content of the soil and rocks where the several samples were collected. Pennsylvanian-age sandstones, shales, and fire clays are the surface rocks in Osage County, where these samples were taken. The flint fire clay and diaspore clay occur within the wide-spread shales and sandstones as funnel-shaped deposits which are fillings in old sink holes and solution pits in the underlying dolomite. Flint clay is composed of kaolinite and halloysite which contains about 40% Al_2O_3. Diaspore pits contain usually flint clay and intermediate burley clays, and diaspore clay which ranges in alumina content from about 70% to 80%.[3] The clay in the surface soil and in the Pennsylvanian shales surrounding the clay pits may be beidellite, illite, or kaolinite mixed with them. The alumina content will run appreciably lower than 40%. Hence, the trees which send their roots into the fire clay are in contact with argillaceous rocks which are notably higher in alumina than those which underlie most of the area.

One may consider trees No. 3, 5, and 8 as growing over the usual type of soil with normal Al_2O_3 content, and as "control" trees. The special comments of the analyst then become significant.

Ash from trees No. 1 and 2 contained more Al than No. 3. Apparently the oaks whose roots went directly into flint fire clay took out more Al from the Al-rich clay than the control a short distance away extracted from ordinary soil. Oak No. 4 apparently took more Al out of a diaspore substrate than a nearby oak took out of a leaner (in Al_2O_3) soil.

Hickory No. 7 over an irony diaspore pit had about twice as much Al in its ash as came from another hickory nearby but outside the pit area. By these comparisons it would appear that trees might serve as good indicators of high alumina clay occurring beneath the surface soil.

However, the relationship appears lesss encouraging when it is noted that there is "more Al in Nos. 4 and 5 than in Nos. 6 and 3." Control No. 5 contained more Al than control No. 3, and also more Al than tree No. 6 which grew on a flint clay pit with a thick 6 foot cover. Apparently the Al extraction of trees from different soils varies within a few miles. Perhaps a detailed comparison of Al contents of oak tree ash with a detailed soil survey might reveal a definite correlation and provide a base level above which higher Al ash contents would be significant. This phase of the problem awaits research.

The alumina content of the tree ash is high enough that analytical methods less sensitive than spectographic are practical and perhaps preferable. The ash from leaves and twigs showed little difference between them and presumably either could be used equally well for botanical-geochemical investigation.

[3] Allen, V. T., Mineral composition and origin of Missouri flint and diaspore clays: Missouri Geol. Survey and Water Resources, 58th Bienn. Rept., 1935. Keller, W. D., Clays of Missouri, *in* Geology of Missouri, by E. B. Branson: University of Missouri Studies XIX, 1944. McQueen, H. S., Geology of the fire clay districts of east central Missouri: Missouri Geol. Survey and Water Resources, Vol. 28, 1943.

Although too few samples were studied to justify drawing an arbitrary conclusion on the use of tree ash as an indicator of the Al content of substrate clay, the very meager evidence furnished by the few presented is somewhat on the promising side.

W. D. KELLER.

UNIVERSITY OF MISSOURI,
COLUMBIA, MO.,
Feb. 1, 1949.

REVIEWS

A Contribution to the Published Information on the Geology and Ore Deposits of Goldfield, Nevada. By FRED SEARLS, JR. Pp. 24; 1 map and 1 section in colors. Nevada Univ. Bull., vol. 42, No. 5, Geology and Mining Series No. 48, Reno, 1948. Price, 50 cents.

This bulletin, only 21 pages long, summarizes the results of the recent work of Searls and his associates of the Newmont Mining Corporation, which has brought to a successful conclusion a long exploration program based on original detailed geologic study and sound geologic reasoning.

The recent work has resulted in several major revisions of the geology of the district as described by Ransome.[1]

The dacite, considered by Ransome to be intrusive in the main part of the district, though present as flows elsewhere, is shown to be a "flow that may be grouped generally with the Milltown andesite series of flows," thus confirming Locke's interpretation.[2]

A major revision of Ransome's geology is that the productive mineralization of the district is shown to have antedated the deposition of the Siebert Lake beds (Siebert formation of Ransome).[3] Ore deposition therefore may have been approximately contemporaneous with that of Tonopah, 25 miles to the north.

The Columbia Mountain fault does not die out south of Columbia Mountain as Ransome had supposed, but turns sharply to the west and continues southward beneath the late Tertiary sediments. Magnetometer surveys, confirmed by later development, have proved the extension of this sub-outcrop over 4,000 feet to the south. Comparison of the cross section of Plate II of this bulletin with section CC′ of Plate VIII of Ransome's Professional Paper shows the resulting revision of structure.

Exploration of the mineralized fault itself did not show sufficient commercial ore to justify mining but gave a new picture of mineralization in the hanging-wall block. The outcropping veins or "ledges" of the district are shown as a linked system branching out southeasterly from the apex of the sharp turn of the Columbia Mountain fault. Most of these veins pinch out in depth; only the Goldfield Consolidated Main vein (Mohawk ledge) reaches, though it does not penetrate, the contact of Tertiary lavas with Cambrian rocks. Here the ore differed greatly from the usual Goldfield type; silver exceeded gold in a ratio of 4 or 5 to 1, and the copper content ranged from 1 to 4 percent, with a trace of tin. It would be of interest to know whether the change to such base ore was gradual, implying zoning such as Nolan found at Tonopah,[4] or so sharp as to suggest the possibility of another source of mineralization.

[1] Ransome, F. L., Geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, 1909; Geology and ore deposits of the Goldfield district, Nevada: ECON. GEOL., vol. 5, pp. 301–311, 438–470, 1910.

[2] Locke, Augustus, The ore deposits of Goldfield: Eng. and Min. Jour., vol. 94, p. 800, 1912.

[3] A name abandoned by the U. S. Geological Survey in favor of Turner's earlier name. Esmeralda formation, of upper Miocene to lower Pliocene age.

[4] Nolan, T. B., Underground geology of the Tonopah mining district: Nevada Univ. Bull., vol. 29, no. 5, p. 45, 1935.

The southward extension of the mineralized fault led to the hypothesis "that the Columbia Mountain fault is the chief source of the Goldfield mineralization." The presumption is that ore-forming solutions, rising along this gently dipping fault, spread laterally into hanging-wall fissures which fanned out from the point of major strain at the bend in the fault. This hypothesis has been satisfactorily confirmed in the recent exploration of the buried southern part of the fault by the Newmont Mining Corporation. Here, at a similar though smaller westward bend in the fault, veins carrying workable ore have been found in the hanging-wall block.

As Searls points out, the determination of the pre-Siebert age of mineralization obviously opens a large area to future exploration, not only along the southward extension of the Columbia Mountain fault, but in the large area to the west, beneath the cover of Siebert lake beds and Malpais basalt. The boulders of ore in the Siebert a mile south of Goldfield suggest the continuation of mineralization dependent on the fault; and the "boulder horizon" in the Siebert, as shown on Plate 1 of the bulletin, persists to a point about three miles south of the most southerly workings indicated on the map.

That mineralization is not confined to the hanging wall of the Columbia Mountain fault is indicated by the rich ore formerly mined at the Sandstorm-Kendall mine in the northern part of the district about 2,000 feet west of the fault. Recent magnetometer surveys, confirmed by drilling, have proved the existence of veins, not yet known to be workable, beneath the Siebert lake beds west of Columbia Mountain.

The proof of relatively early mineralization at Goldfield seems to the reviewer to have wide implication. Twenty years ago I attempted a genetic classification of Nevada ore deposits.[5] The ore deposits associated with Tertiary lavas were placed in two groups: the older group, chiefly valuable for silver, of which Tonopah was considered typical, was inferred to be genetically associated with lavas of pre-Siebert age, and the younger, predominantly gold deposits, with lavas later than the lake beds. This classification was accepted by Nolan and applied to epithermal precious-metal deposits of all the western states.[6] He notes, however, "Ferguson's suggested age relations probably do not hold throughout this larger area."[7] In my paper it was noted that the deposits of the younger group were in general less productive than those associated with the lavas of pre-Siebert (pre-Esmeralda) age, but Goldfield was cited as an outstanding exception to this generalization. Other examples cited of the supposed productive late gold mineralization have likewise proved erroneous; the existence of the "younger veins" of Tonopah[8] has been disproved by Nolan;[9] and more detailed field work has shown the pre-Esmeralda age of the gold veins of the Omco district, west of Tonopah.[10] It may be that at Manhattan[11] I have made the same mistake as Ransome and confused the age of uneconomic mineralization in the younger lavas with that of the productive deposits in the older rocks.

[5] Ferguson, H. G., The mining districts of Nevada: ECON. GEOL., vol. 24, pp. 115–148, 1929. Reprinted with "postscript" in Nevada Univ. Bull., vol. 38, no. 4, pp. 78–108, 1944.

[6] Nolan, T. B., Epithermal precious metal deposits, *In* Ore deposits of the Western States, Lindgren Volume, Am. Inst. Min. Met. Eng., pp. 623–640, 1933.

[7] Idem, p. 624.

[8] Spurr, J. E., Geology of the Tonopah mining district, Nevada: U. S. Geol. Survey Prof. Paper 42, p. 99, 1905.

[9] Nolan, T. B., The underground geology of the western part of the Tonopah district: Nevada Univ. Bull., vol. 24, no. 4, 1930.

[10] Ferguson, H. G., "Postscript," p. 107, Nevada Univ. Bull., vol. 38, no. 4, 1944.

[11] Ferguson, H. G., Geology and ore deposits of the Manhattan district, Nevada: U. S. Geol. Survey Bull. 723, 1924.

The proof of earlier mineralization at Goldfield strengthens the inference that in Nevada the principal period of mineralization associated with the Tertiary lavas was prior to the widespread deposition of the sediments of upper Miocene to lower Pliocene age (Rosamond, Barstow, Esmeralda, Siebert, Truckee, etc.), although some production, principally gold, has come from deposits to which a later age can be assigned. Careful study and mapping of the lava sequence in selected areas, such as the 25-mile belt between Goldfield and Tonopah and the Aurora-Bodie area, might therefore prove of value. Ransome [12] has shown the futility of expecting a lithologic sequence to persist over the Great Basin as a whole; but within limited areas, knowledge of the succession of groups of flows separated by unconformities, and of the age relations of accompanying intrusives and the presence of pre-Pliocene structural features such as the Columbia Mountain fault and the faults at Tonopah, might be of direct value.

H. G. FERGUSON

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
March 9, 1949.

Gesteine und Minerallagerstätten. Bd. I, Allgemeine Lehre von den Gesteinen und Minerallagerstätten. By PAUL NIGGLI. Pp. 540; figs. 335. Verlag Birkhauser, Basel, 1948. Price, 42 Swiss francs (unbound), 46 Swiss francs (bound).

This book is the first of three volumes; the second, "Die exogenen Gesteine und Minerallagerstätten," was ready for publication in December, 1947; and the third, "Die endogenen Gesteine und Minerallagerstätten," is in preparation.

The present volume deals with the fundaments of our knowledge of rocks and mineral deposits and is therefore restricted to a consideration of general principles. According to the author no similar type of treatment has ever been previously undertaken. As such a pioneer attempt, it is of the highest interest.

The book is divided into four parts. Part I deals with the material foundations of the lithosphere. The fundamentals of geochemistry and crystal chemistry are briefly given and the most important minerals are briefly described, with special emphasis on their ionic structure. The illustrations are particularly fine.

Part II (Das Gefüge) deals with the textural and structural features of rocks. Fabric (Gefüge) is used in the broad sense of Sander to include all spatial data in regard to rocks, whatever the magnitude of the parts may be. New, broad, rock-class names have been coined, *e.g.*, ophthalmites, which embraces all rocks that contain lenses, eyes, pebbles, or nodules embedded in a matrix, such as augen gneisses, conglomerates, et al.; stromatites, any layered rock, folded or unfolded; and others. This portion is well illustrated. For beginners the treatment is too brief and too advanced. A condensed account of petrofabric analysis is given. The final section discusses porosity and the technical properties of rocks and their relation to mineral composition and fabric.

Part III deals with the physico-chemical factors that control the formation of minerals and mineral deposits. It begins with the laws of the stability and co-existence of minerals in mineral aggregates. The phase rule is used to elucidate these problems, and its value in determining parageneses is treated at considerable length. The processes effective in forming minerals are next considered, including crystallization, from solutions, unmixing in the liquid and solid states, distillation processes, and chemical kinetics.

[12] Ransome, F. L., op. cit., p. 105.

The geophysical foundations of our knowledge of rocks and mineral deposits are considered in Part IV, in which Dr. Niggli has been aided by his son Ernst Niggli. The geothermal gradient and allied facts are presented. The electrical and magnetic properties of rocks are outlined, supported by the known quantitative determinations. The methods of applied geophysics—gravimetric, seismic, electric and electromagnetic, magnetic, and radioactive—are given. In conclusion a systematic classification of rocks and mineral deposits is presented. It divides all rocks and mineral deposits into two classes: the exogene and the endogene. The exogene comprise the autochthonous deposits formed by weathering, and the endogene comprise (1) katathermal, inclusive of part of the mesothermal, and (2) the epithermal, inclusive of part of the mesothermal, rocks and mineral deposits. Finally, a selected bibliography is appended. The book is a signal achievement in its extraordinarily wide scope and its broad philosophical treatment.

ADOLPH KNOPF.

Grundwasserkunde, 2nd Edit. By W. KOEHNE. Pp. 314; figs. 128; numerous tables. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1948. Price, $7.50.

The first edition of this book appeared in 1927 and the present edition brings the subject matter up to date in a subject in which so much new material has been contributed in recent years. The 12 chapters cover broadly the whole subject of groundwater and its principles—definitions, infiltration, water table, underground flowage, water temperature, chemical character, domestic and industrial supplies, relation to plants and surface features. The book contains a 27-page bibliography that is now somewhat out of date. Apparently the voluminous recent American literature and advances have not been available to the author.

Map of the Americas, 1: 5,000,000. In color, accompanied by 2 Indices. American Geographical Society, New York. Price, map $4.00 per sheet; indexes, to Latin American sheets $0.50, to northern sheets $1.00.

This excellent map of the Western Hemisphere was begun at the outbreak of World War II. Each sheet is 46 in. × 35 in. and is in colors. There are three Latin American sheets, one covering Mexico, Central America and the West Indies, and two covering South America. These three sheets were prepared from the Society's "Map of Hispanic America, 1:1,000,000," the excellence of which has been known to all who have used it. An index to accompany these three sheets was prepared in 1942.

The two northern sheets consist of United States and Southern Canada, and Northern Canada, Alaska and Greenland. These were compiled from large-scale official maps, supplemented by much additional material, including the latest mapping by aerial photography. This is the first general map of the United States with such topographical details. The Northern Arctic sheet gives details obtained from aerial photography never before available. An index to these two sheets was prepared in 1948.

The sheets show topography and elevation by formlines and colors. They show railroads, airports, state and international boundaries, civil divisions, towns, roads, and important physical features. The indexes list all town names, states, provinces, colonies, hydrographical names and other physical names, all of which can be located by coordinates on the respective sheets.

These maps represent another of the excellent services performed by the American Geographical Society.

Examination and Valuation of Mineral Property, 3rd Edition. By ROLAND D. PARKS. Pp. 504; figs. 48; tables. Addison-Wesley Press, Inc., Cambridge 42, Mass. Price, $5.00.

This third edition of the formerly well-known pocket book "Mine Examination and Valuation" by Baxter and Parks now appears in expanded form under a new title. Major additions include a chapter on Valuation of Oil Property by W. L. Whitehead and one on The Michigan Mine Appraisal System by F. G. Pardee.

The subject matter consists of discussions of mine examinations, planning of work, sampling calculations and practices, ore estimation and estimation of costs and profits. Mine valuation is considered under the various phases of discounts, annuities, amortization, depletion, Hoskold and other valuation methods, and non-uniform income. Extensive valuation, annuity, and interest tables are given. An extensive bibliography is given.

This book will need to be in the library of all valuation mining engineers and economic geologists.

BOOKS RECEIVED.

ALAN T. BRODERICK.

U. S. Geological Survey—Washington, D. C., 1949.

The Daisy Fluorspar Deposit near Beatty, Nye County, Nevada. W. R. THURSTON. Pp. 10; figs. 2; pls. 12. Strategic Minerals Investigations Prel. Rept. 3–209. *Fluorspar occurs as fillings along faults in Paleozoic limestone. 100,000 tons of 75% CaF_2 estimated reserves. Inferred reserves probably large but are not estimated.*

Geology of the Glendo Area, Wyoming. J. D. LOVE, N. M. DENSON, AND THEODORE BOTINELLY. Oil and Gas Investigations Prel. Map 92 (2 sheets). *Geologic map, 1" =4000', composite stratigraphic section. Possible oil-bearing areas are indicated. Rocks are largely of Mississippian, Pennsylvanian, Permian, and Triassic age.*

Use of Sulphitic Liquid to Reduce the Resistance of Quartzose Rocks to Drilling. E. LEMAIRE; translation No. 12 by SEVERINE H. BRITT. Pp. 6; fig. 1. *Quartzitic rocks show 1.43 to 1.62 times as much abrasion loss when cut under sulphitic liquid rather than water.*

U. S. Bureau of Mines—Washington, D. C., August 1948–March 1949.

Mineral Trade Notes, Vol. 27, No. 2. Pp. 50. *A monthly inventory of information from U. S. Government Foreign Service offices and other sources that may not otherwise be made available promptly.*

Spec. Suppl. 28 to Vol. 27, No. 2. Gold and Silver Mining Industry of Japan. ROBERT Y. GRANT. Pp. 10; figs. 2; tbls. 4. *Statistics.*

Rept. Inv. 4416. Investigation of Whiteware Clay Deposit, Fergus County, Mont. R. N. ROBY AND ALMON F. ROBERTSON. Pp. 11; tbls. 3; figs. 3. *Masses of pure dickite formed by replacement of sedimentites along fracture zones. Suitable for ceramics.*

Rept. Inv. 4415. Investigation of Zinc-Lead Deposits on Extensions of the Miami Trough, Ottawa County, Okla., and Cherokee County, Kans. CLINTON C. KNOX. Pp. 8; figs. 8; drill hole logs.

Rept. Inv. 4421. Investigation of Muir Inlet or Nunatak Molybdenum Deposits, Glacier Bay, Southeastern Alaska. R. S. SANFORD, G. A. APELL, AND F. A. RUTLEDGE. Pp. 6; figs. 8. *Large low-grade stockwork. Few samples give more than .15% Mo. Average is .07%; highest is .52%.*

Rept. Inv. 4423. Investigation of Cheever Limonite Deposit, Berkshire County, Mass. R. J. BURGESS AND ROBERT S. SANFORD. Pp. 13; figs. 7; tbls. 10.

Rept. Inv. 4425. Investigation of Portland Beryl-Mica District, Middlesex County, Conn. M. F. BOOS, E. E. MAILLOT, AND MCHENRY MOSIER. Pp. 8; figs. 21; drill hole logs.

Rept. Inv. 4426. Investigation of Talladega Gray Iron Ores, Talladega County, Ala. DONALD F. REED. Pp. 10; figs. 10; drill hole logs and assays. *Hematite bodies in quartzites and phyllites. Drilling shows them to decrease in thickness with depth.*

Rept. Inv. 4427. Investigation of Certain High-Alumina Clays of Central Pennsylvania. ROBERT S. SANFORD. Pp. 12; figs. 4; tbls. 6.

Rept. Inv. 4375. Missouri Valley Manganese Deposits, South Dakota. Pt. 1. General Investigations, Stratigraphic Studies, and Tonnage and Grade Estimates. PAUL E. PESONEN, EDWARD L. TULLIS, AND PAUL ZINNER. Pp. 90; tbls. 43; figs. 20. *12 to 80 feet thick Upper Cretaceous shale member contains 1 to 8% nodules which in turn contain 4 to 25% Mn. Enclosing shale contains 1% Mn. An outcropping and lightly covered zone 523 miles in peripheral length and 365 feet wide contains 12,000,000 tons of Mn in 77,700,000 tons of concretions. The shale in the same zone contains an equal or greater amount of Mn in lower grade material.* **Rept. Inv. 4428. Pt. II. Drill-Hole Logs and Sections.** Pp. 4; sections 48.

Rept. Inv. 4432. Magnetic Surveys of Certain Magnetite Deposits in New Jersey. Pt. II. Morris, Passaic, Sussex, and Warren Counties. J. A. STAMPE, MCHENRY MOSIER, AND OTHERS. Pp. 7; figs. 42. *Results of 533,000 linear feet of dip-needle traverses, some of which were supplemented by sun dial compass surveys.*

Rept. Inv. 4433. Investigation of Sweetsprings Manganese Deposits, Monroe County, W. Va., and Craig County, Va. HAROLD B. EWOLDT AND ROBERT S. SANFORD. Pp. 5; figs. 11. *Minor deposits of nodular manganese in clay.*

Rept. Inv. 4434. Investigation of Douglas Fluorite Property, Pope County, Ill. O. M. BISHOP AND A. B. NEEDHAM. Pp. 8; drill hole logs. *Negative results of 3,578 feet of core drilling.*

Illinois State Geological Survey—Urbana, 1949.

Rept. Inv. 136. Analysis of Coal Cleaning on a Concentration Table. CHARLES C. BOLEY. Pp. 63; tbls. 34; figs. 14.

Rept. Inv. 140. Illinois Mineral Industry in 1947. WALTER H. VOSKUIL. Pp. 91; tbls. 66; figs. 19.

Circ. 150. Prospects for Oil Discoveries in Illinois beyond Proven Areas and from Deeper Horizons. ALFRED H. BELL AND M. M. LEIGHTON. Pp. 5; figs. 10.

Ground Water in Southwestern Kansas. JOHN C. FRYE AND V. C. FISHEL. Pp. 24; pls. 2; figs. 5. Kansas Geol. Survey, Lawrence, 1949. *Written for the layman.*

Pre-Upper Cambrian Sediments of Vernon County, Missouri. MARGARET W. SKILLMAN. Pp. 18; pls. 2. Missouri Geol. Survey, Rept. Inv. 7, Rolla, 1948. *Cuttings from 2 deep wells show 1245-foot section of Pre-Upper Cambrian quartzite, siltstone and shale.*

Barite of New Mexico. DONN M. CLIPPINGER. Pp. 28. New Mexico Bur. Mines Circ. 21, Socorro, 1949. *Minor deposits containing considerable fluorite occur as fissure fillings.*

Water in Ohio—Summary and Prospects 1949. C. V. YOUNGQUIST. Pp. 39. Ohio Water Resources Board Bull. 20, Columbus, Feb. 1949.

Oregon Department of Geology and Mineral Industries—Portland, 1949.

Bull. 40. Preliminary Description of the Geology of the Kerby Quadrangle, Oregon. FRANCIS G. WELLS, PRESTON E. HOTZ, AND FRED CATER, JR. Pp. 23; colored geol. map, 1:96,000. *Quadrangle contains chromite pods in dunite; minor cobalt, copper, gold, manganese, nickel, platinum, pyrite, mercury, silver, and zinc.*

G.M.I. Short Paper 18. Radioactive Ores the Prospector Should Know. DAVID J. WHITE. Pp. 14; fig. 1.

Texas Bureau of Economic Geology—Austin, 1948–1949.

Rept. Inv. 5. Iron Ore in the Llano Region, Central Texas. VIRGIL E. BARNES, SAMUEL S. GOLDICH, AND FREDERICK ROMBERG. Pp. 50; figs. 9; pls. 8. *Small deposits in Precambrian metamorphic rocks investigated with dip needle, gravity meter and diamond drill.*

Pub. 4824. Geological Resources of the Trinity River Tributary Area in Oklahoma and Texas. EDITED BY A. E. WEISSENBORN AND H. B. STENZEL. Pp. 252; figs. 33.

Geology of Ribbon Creek Area, Alberta. M. B. B. CROCKFORD. Pp. 67; figs. 13; tbl. 1; colored geol. map, 1″ = 1 mile. Research Council of Alberta Rept. 52, Edmonton, 1949. *Considerable reserves of low volatile bituminous to semi-anthracite Cretaceous coal.*

Newfoundland Geological Survey—St. John's, 1948–1949.

Bull. 32. Pt. I. Geology of the Area Between Bonavista and Trinity Bays, Eastern Newfoundland. A. O. HAYES. **Pt. II. Geology of the Area Between Bonavista, Trinity, and Placentia Bays, Eastern Newfoundland.** E. R. ROSE. Pp. 49; pls. 6; figs. 13; tbls. 7.

Inf. Circ. 6. Coal Possibilities of Newfoundland. A. O. HAYES. Pp. 31. *Although numerous coal horizons are present, none can be worked profitably at present.*

Ontario Department of Mines—Toronto 1949.

Vol. 55, Pt. 5, 1946. Sandstone as a Source of Silica Sands in Southeastern Ontario. M. L. KEITH. Pp. 36; photomicrographs 6; figs. 5; pls. 6.

Vol. 56, Pt. 7, 1947. Geology of Beatty Township. J. SATTERLY AND H. S. ARMSTRONG. Pp. 34; ills. 7; fig. 1; colored geol. map, 1″ = 1000′. *Area*

contains small gold deposits as quartz veins and as zones of replaced wall-rocks.

Vol. 57, Pt. 4, 1948. Geology of Michaud Township. J. SATTERLY. Pp. 27; ills. 10; fig. 1; colored geol. map, 1″ = 1000′. *Reported results of considerable drilling show only traces of gold mineralization.*

Geology of the Northern Pennine Orefield, Vol. 1. K. C. DUNHAM. Pp. 357; figs. 33; pls. 4. Great Britain Geol. Survey, London 1948. *Detailed mine-by-mine descriptions of this old lead district.*

Departamento Nacional da Produção Mineral—Rio de Janeiro, 1946–1948.

Bol. 24. Investigações Químico-Analíticas. FRITZ FEIGL, PHILIP W. WEST, HANS E. FEIGL, ARYKOERNER GUERREIRO, MARIA YELDA E. RAMOS, IEUDA CIORNAI, AND AIDA ESPÍNOLA. Pp. 76. *New methods of qualitative and quantitative analyses of selenium, titanium, chromium, cobalt, and tin.*

Bol. 27. Investigações Químico-Analíticas. FRITZ FEIGL, PHILIP W. WEST, CASSIO MENDONÇA PINTO, ARYKOERNER GUERREIRO, LUIZ B. DE ARAUJO, NISSIN CASTIEL, DAVID GOLDSTEIN, AND ILSE DOROTÉA RAACKE. Pp. 129. *Articles on the masking effects by hydrogen peroxide on molybdenum, vanadium and tungsten; a new test for paladium; quantitative analysis of traces of phosphorus; determination of molybdenum in scheelite.*

Bol. 29. Relatório do Director, 1946. MÁRIO DA SILVA PINTO. Pp. 61.

Sulla Distribuzione delle Temperature nella Genesi dei Giacimenti di Origine Magmatica. FILIPPO FALINI. Pp. 51; figs. 14; tbl. 1. Rome, 1948. *Distribution of the temperature in the genesis of deposits of magmatic origin.*

Estudos, Notas e Trabalhos, Vol. 4, Fasc. 1. Pp. 64; numerous illustrations. Portugal Direcção Geral de Minas e Servicos Geológicos, Porto, 1948. *7 separate papers on Portugal's lead and zinc deposits; serpentinization; iron deposits of southern Portugal; montmorillonite in granitic pegmatites and the problem of montmorillonitization.*

Miscelánea Almera. Pp. 354; numerous illustrations. Instituto Geológico de Barcelona, 1948. *Contains 133-page article on the Cataluña coal field.*

SCIENTIFIC NOTES AND NEWS

CHAS. H. BEHRE, JR., returned some time ago from Rangoon where, as representative of Behre Dolbear and Company, mineral advisers to the Burma Union Government, he discussed general plans for mineral development. His trip involved a round-the-world flight. He has now resumed field work in Mexico.

FREDRICK KRUGER will join the staff of the Department of Geology and Geography at the University of Tennessee as Associate Professor in Geology commencing with the Fall Quarter, 1949. Dr. Kruger, for many years associated with the Cerro de Pasco Copper Corporation in Peru, was Visiting Lecturer at Northwestern University for the past academic year.

WILLIAM B. MATHER, economic geologist, has been appointed Chairman of Mineral Technology at Southwest Research Institute in Houston and San Antonio, where he will be in charge of ceramics, metallurgy, mineralogy, and geology.

The Institution of Mining and Metallurgy, London, announces that a Symposium on the Refining of Non-Ferrous Metals took place at the Royal Institution of Chartered Surveyors on July 7 and 8.

JAMES M. HILL, formerly geologist with the Union Carbide and Carbon Company, has opened his office as Consulting Mining Geologist at 182 North Court St., Tucson, Ariz.

D. F. HEWITT has left the University of Wisconsin and joined the Ontario Department of Mines staff.

DONALD H. MCLAUGHLIN has been appointed chairman of the National Committee of sponsors of the Harvard Foundation for Advanced Study and Research.

ALAN M. BATEMAN has returned from Japan where he initiated, for NRS, GHQ, SCAP, geologic programs for the development and exploration of mineral resources to aid Japanese economy.

BLAKEMORE E. THOMAS of the California Institute of Technology has been appointed Assistant Professor of Geology at the University of Kansas, Lawrence, where he will teach petrography and economic geology.

ARTHUR E. BULLER, formerly Resident Geologist for the Kelowna Exploration Co. at the Nickel Plate Mine, Hedley, B. C., has accepted the position of Chief Geologist for the Pend Oreille Mines and Metals Co. at Metaline Falls, Washington.

E. S. MOORE, Head of the Department of Geological Sciences, University of Toronto, and formerly Dean of the School of Mines, Pennsylvania State College, retired on June 30 with the title of Professor Emeritus after twenty-seven years on the staff.

A. N. SAYRE, geologist in charge of the Ground Water Branch of the Water Resources Division of the U. S. Geological Survey, was awarded the honorary degree of Doctor of Science on June 6 at the commencement exercises of Denison

University, Granville, Ohio. The citation read as follows: "To Albert Nelson Sayre, valued servant of his country in peace and in war, and holder of her 'Medal of Freedom,' in recognition of his rewarding pursuit of life-giving water and his able disclosing of Earth's hidden secrets."

DAVID M. DELO, of Washington, D. C., is the first Executive Director of the American Geological Institute, Dr. Detlev W. Bronk, Chairman of the National Research Council, announced. The American Geological Institute is a new organization established in November 1948 which will represent the profession of geology. It is composed of a union of eleven geological societies whose members total more than 10,000 professional geologists. Headquarters will be located in the National Research Council, 2101 Constitution Ave., Washington 25, D. C., and the activities of the Institute will be carried on in conjunction with those of the Division of Geology and Geography, NRC. The primary objectives of the new Institute are the advancement of geology and its application to human welfare by providing a means for the cooperation of organizations active in the fields of pure and applied geology. Membership is open to all non-profit organizations concerned with the earth sciences. Officers of the Institute are A. I. Levorsen, Stanford University, president; W. B. Heroy, Dallas, Texas, vice-president; and Earl Ingerson, U. S. Geological Survey, Washington, D. C., secretary-treasurer.

A Conference on Radioactive Ores, sponsored by the Upper Peninsula of Michigan Mineral Industries group, was held in Houghton, Michigan, on May 6, at the Michigan College of Mining and Technology. Dr. Phillip L. Merritt of the U. S. Atomic Energy Commission discussed pitchblende, the primary source of uranium. Dr. A. H. Lang of the Geological Survey of Canada spoke on Canadian uranium deposits. Other speakers were Drs. Muriel Mathez and Donald L. Everhard of the U. S. Atomic Energy Commission, C. Ernest Kemp, and Dr. A. K. Snelgrove.

The District Office for the ground water investigations of the U. S. Geological Survey for the New York-New England area has been moved from the Post Office Building in Jamaica, N. Y., to 222 Old Country Road, Mineola, N. Y.

DONALD M. DAVIDSON has been elected vice-president of E. J. Longyear Company, Minneapolis, Minn.

A Committee of the British Petroleum Industry, by invitation of Oxford University, held "An Exhibition of Oilfield Development" in the new building of the Department of Geology and Mineralogy at Oxford from July 8th to July 20th, 1949.

C. E. JACOB has taken leave from the University of Utah, where he served as Head of the Department of Geophysics, to enter consulting practice in Salt Lake City and will specialize in Ground-Water Engineering and Subsurface Exploration. For eleven years Mr. Jacob was with the Ground Water Branch of the U. S. Geological Survey, working in New York, Illinois, Texas and Florida.

The tentative program for the three-day commemoration of the seventy-fifth anniversary of the Colorado School of Mines, September 29 and 30, and October 1, at Golden, has just been released by Harry M. Crain, chairman of the executive committee for the celebration. Listed are discussions of vital problems by outstanding authorities in every phase of the mineral industry. Lists can be obtained by writing to the Department of Public Relations, Colorado School of Mines, Golden, Colo.